# BIOLOGY

H. MUNRO FOX

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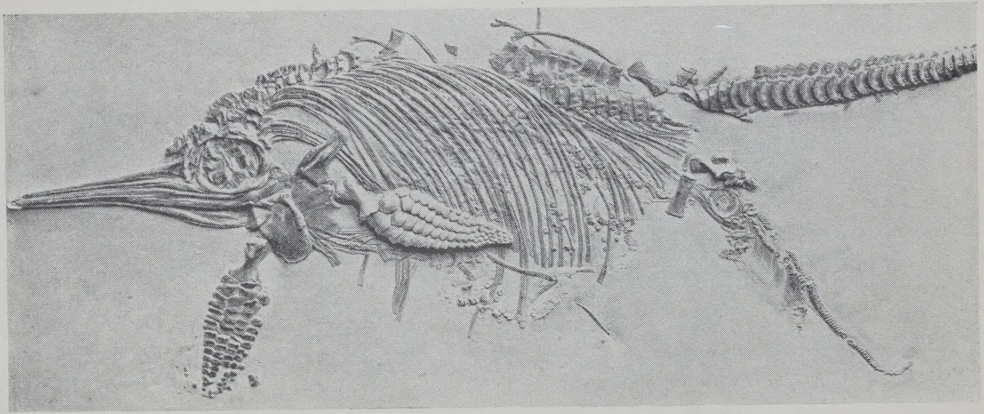

*Frontispiece.* Skeletons of a reptile which lived in the sea and of its young. These animals are now extinct. They lived over 100 million years ago. (See p. 294.)

101

# BIOLOGY

## An Introduction to the Study of Life

BY

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*and formerly Fellow of*
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*To*

J. STANLEY GARDINER

# PREFACE

ROBERT BOYLE, in the seventeenth century, said: "It is highly dishonourable for a reasonable soul to live in so divinely built a mansion as the body she resides in altogether unacquainted with the exquisite structure of it". This is no less true to-day, and for an acquaintance with the structure of our body a foundation of biology is essential.

Moreover, our civilization is founded largely on biology. Hygiene, medicine, agriculture and the study of populations are biological sciences. It seems obvious, therefore, that biology should form a part of the education of the future citizen. Yet Great Britain is at present the only important country in Europe in which some biology is not taught to everyone at school. But the tide seems now to be turning, and the study of biology is being introduced every year into more and more schools.

This book is designed to meet the need of such biological teaching. Examinations are an unfortunate necessity, and the book has been written in part to conform with the requirements of the School Certificate Examination, and of Biology as a Subsidiary Subject in the Higher Certificate. All the animals and plants mentioned in the various syllabuses for the School Certificate have been dealt with. But it is hoped that the book may also provide a readable outline of biology for those of more mature years who are not studying for any examination.

There are different ways of creating an interest in biology. Some teachers think that it is best to begin with the most familiar animal, man. Boys and girls are interested in their own bodies and how they work. Others would excite the student by the unfamiliar. *Amoeba* and the strange world of the microscope may be taken first. Many young people commence studying nature on their own account. I myself, for example, kept aquaria at Brighton with marine animals in them, and dug fossils out of the chalk pits in the Sussex downs. My literature was Philip Gosse and Lyell, and later Huxley and Haeckel. When natural history is already a hobby it does not matter where we begin to teach the science. The interest is already there. In this book I have chosen the way of starting with man and of ending with fossils, going through the range of animals and plants between these extremes.

The different School Certificate syllabuses vary considerably in the particular plants and animals recommended for study. This book has been written so that in a number of cases alternative types are described. The teacher can leave out parts of the book as he thinks fit. Thus, either the cockroach or the crayfish, either the liverwort or the moss, may be taught. Omitting one or the other does not interrupt the argument running through the book.

I have introduced certain aspects of biology which do not come into any of the examination syllabuses. At the discretion of the teacher they may be omitted. But in my opinion there are certain newer aspects of the science which are now on a sufficiently sure footing to be profitably taught in an introduction to biology. Among these are growth and development, tissue culture, internal secretions, and present-day views of instinct and intelligence.

The last two chapters are on Evolution and on The

History of Biology. Evolution is the main idea behind the science of biology. It affects the whole modern outlook on the world, and without an understanding of the evolutionary point of view biology is meaningless. It is equally impossible to have a true perspective of the science without knowing in outline how it has gradually developed and advanced in the course of human history.

A word must be added on the method of teaching. Great pains have been taken to reduce the number of technical terms to a minimum. Many such terms which are often taught to beginners are a useless burden on the memory. And, throughout, stress is laid on the practical side. Wherever possible, animals and plants should be examined and studied by the students themselves. Dissections should be made and experiments set up by the teachers and shown to the pupils. The importance of field work is too obvious to be stressed. Animals and plants must be seen in their natural habitats. And the establishment of aquaria is very desirable. In an aquarium you have a small enclosed environment where the balance of nature can be appreciated. The instructions at the end of each chapter are addressed to the teachers. Practical work with marine organisms has been omitted, since so many schools are remote from the sea. But those more fortunately placed in this respect can easily adapt or supplement their practical work, making use of life on the sea shore.

In conclusion, I wish sincerely to thank a number of friends who have helped me in the preparation of the book. Mr J. W. Stork has placed at my disposal his valuable experience of different ways of teaching biology. Mr C. G. C. Chesters has greatly helped me by reading the proofs of the botanical chapters. Dr R. Wurmser and Mr H. G. Newth have rendered me like services with Chapters II and XX respectively. In writing the last chapter I have made use of Dr Charles Singer's excellent book, *A Short History of Biology*. Prof. E. R. Dodds has been good enough to assist me with the Appendix. The following ladies and gentlemen have very kindly given me photographs to reproduce as plates: Dr R. G. Canti, Mr C. G. C. Chesters, Mr J. Gray, F.R.S., Dr Bierens de Haan, Prof. L. T. Hogben, Prof. D. Keilin, F.R.S., Dr W. Leach, Mr J. F. Marshall, Mr F. G. Spear, Miss S. M. Stephenson, Prof. F. Vlès, and Mr D. P. Wilson.

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# CONTENTS

*Chap.* I. Life and energy . . . . . *page* 1

II. Respiration . . . . . . . 11

III. Blood . . . . . . . 17

IV. The frog . . . . . . 25

V. Protoplasm and cells . . . . 41

VI. How green plants feed . . . . 59

VII. Colourless plants . . . . . 77

VIII. The lower green plants . . . . 91

IX. *Hydra* and worms . . . . . 109

X. Insects . . . . . . . 126

XI. Flowers . . . . . . . 157

XII. Fruits and seeds . . . . . 173

XIII. Germination and growth . . . 179

XIV. Buds and bulbs . . . . . 199

XV. The animal kingdom . . . . 213

XVI. Growth and death . . . . . 251

XVII. Instinct and reason . . . . 263

XVIII. Fossils . . . . . . . 282

XIX. Evolution . . . . . . 299

XX. The history of biology . . . . 317

*Appendix.* Greek and Latin derivations of words . 333

*Index* . . . . . . . . . 337

## CHAPTER I

# LIFE AND ENERGY

BIOLOGY is the science of life. It is the study of life in man, in other animals and in plants. The branch of biology dealing with animals is called zoology. Botany is the part of biology which deals with plants. Strictly speaking, human history, too, is included in biology. For many of the main truths which the science of biology has made clear apply to man, and the past history of the human race is closely linked up with that of animals.

Living things are all either animals or plants, and there is not so much difference between the two as appears at first sight. Man himself is an animal, and so too are dogs, frogs, fishes, snails, insects, worms, jelly-fish and other smaller creatures which are invisible to the naked eye. Familiar plants are trees, buttercups, grasses, ferns, mosses and seaweeds. But green pond-scums and moulds are also plants, as so, too, are microbes or bacteria.

ENERGY. We all know that one of the most obvious signs of life is *movement*. Animals walk, or fly, or swim. Yet it is not only animals that move. Plants move too. Many flowers, for instance, close at night (Fig. 1 and Exp. 1), and there are leaves which move so that their parts are at different angles to one another at night and in the daytime. Clover leaves behave in this way (Exp. 2). A second characteristic of life in all plants and animals is *growth*. Now, the accomplishment of these two signs of life, movement and growth, requires the expenditure of *energy*, and we shall start by looking into the question of where living things get their energy and how they use it.

Energy, we are taught by physics, is that which does work. Compressed steam possesses energy, and it does work in forcing a piston down a cylinder and so driving an engine.

Likewise the human body possesses energy which does work in walking—or merely in talking.

Energy exists in two forms. These are called *potential* and *kinetic*. Potential energy is a store of energy that can do work; kinetic energy actually does work. The one kind can be changed into the other and *vice versa*. When the spark flashes in the cylinder of a motor-car, the potential energy of petrol vapour plus air is changed into kinetic energy which does work. If you lift a weight from the floor on to the table, you do work, that is you expend kinetic energy. This energy is stored as potential energy in the raised weight. If the weight is allowed to fall again, its

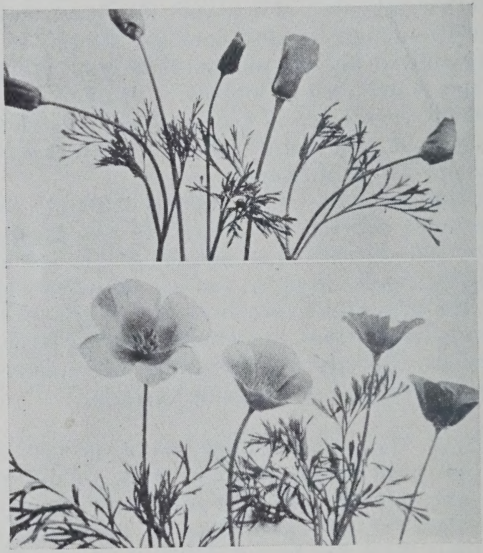

Fig. 1. *Flowers which close at night and open in the daytime*. (R. H. Yapp.)

potential is turned into kinetic energy in falling. By some arrangement of strings and pulleys this kinetic energy could be made to do work. An animal or a plant contains potential energy, which, inside the body, can be turned into kinetic energy and so do work.

Energy shows itself in a number of different states which are familiar to all of us. It may be mechanical energy, such as walking or the movement of an engine. It may be heat energy, or light, or electricity. Or again, energy may be chemical. We saw a case of chemical energy in the petrol vapour. And it is a store of *chemical* energy in ourselves that makes us move.

Movement is *mechanical* energy, and living things set free energy in this form. But not only in this form. It may also be freed as *heat* energy. Our bodies are warm, the bodies of insects warm up as they fly, and even plants produce heat. The steaming of a dung heap is due to microbes, and growing peas set energy free as heat (Exp. 3). And more than this, some creatures give out energy as *light*. The glow-worm is a case in point, and also the

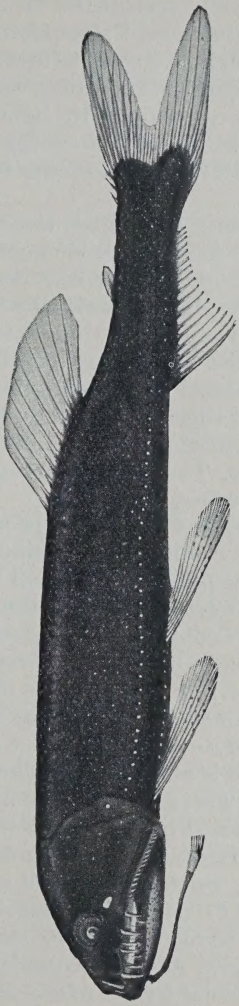

Fig. 2. *Deep sea fish that produces light*. The white spot behind the eye and the line of spots along the fish's side glow with light.

light often seen at the surface of the sea. This is sometimes wrongly called "phosphorescence", but it is really caused by small living creatures, and has nothing to do with phosphorus. Some deep-sea fishes have patches along their bodies glowing with light like the portholes of a liner (Fig. 2). *Electrical* energy may also appear. The torpedo is a fish that electrocutes its enemies.

FOOD. In animals the supply of energy enters the body in the food which is eaten. Food is made up of chemical compounds which contain in them a supply of potential energy. Inside our bodies this energy is turned into kinetic energy, and with this change work is done, for example by muscles. The energy in petrol vapour is set free in a motor, and likewise the energy in food is liberated in the body.

But this is not the only reason why we eat. There are two reasons why living things require food. One is to provide *energy*. The other is to supply the *raw materials for growth and repair*.

The *food of animals* is composed in part of very complicated chemical compounds. But all the food-substances can be put under a small number of headings.

(1) *Carbohydrates* are the first group. These are compounds which contain the elements *carbon*, *hydrogen* and *oxygen* combined together in a particular way. *Sugar* is one of them, but perhaps the most abundant is *starch*. This is contained in very many of our foods. It forms the bulk of potatoes and bread. *Cellulose* is another carbohydrate which is abundant in plants.

(2) *Fats* also are made up of *carbon*, *hydrogen* and *oxygen*, combined in a different way. Butter and the fat of meat are examples. Vegetable and animal oils, too, belong to this class. Such are olive oil and cod-liver oil.

(3) *Proteins* are the most complicated compounds in food. The elements *carbon*, *hydrogen*, *oxygen*, and in addition *nitrogen*, are here combined to form huge molecules. The molecular weight of one of them, 70,000, will show you how

big the molecules are, when you think that the molecular weight of carbon dioxide is only 44 and that of water 18. Proteins are present in all plants and animals, so that they are contained in all foods of man and animals. They are especially abundant in meat.

(4) *Vitamines* form another group of food substances. They are needed in very small amounts, but we cannot do without them.

(5) Certain *salts*, too, are necessary. They furnish *sodium*, *potassium*, *calcium*, *magnesium*, *chlorine*, *sulphur* and *phosphorus*, all of which form part of the living substance. In addition small amounts of compounds containing *iron* and *copper* are essential.

(6) Finally, *water*, as we all know, must be drunk. Not only is it needed for blood, but also to build the rest of the living substance of the body, which is made up largely of water with proteins, carbohydrates, salts and other compounds dissolved in it.

DIGESTION. The food which animals such as man or a frog eat passes through the mouth into a tube called the *alimentary canal* or gut (Exp. 4). The alimentary canal includes the stomach and the intestine. Water and salts can pass through the wall of this canal into the blood. But the other classes of foods will not pass through until they have first been changed. The change consists in the breaking down of their large molecules into smaller molecules which are more soluble in water.

This change which the food undergoes in the alimentary canal is called *digestion*. Digestion is brought about by certain chemical substances in solution. The solutions are poured on to the food in various parts of the alimentary canal.

Digestion begins in the *mouth*, where the digestive liquid is called *saliva*. It goes on in the *stomach* (Fig. 3) with the help of a solution known as *gastric juice*. Digestion continues in the next part of the alimentary canal, the *intestine*, which is a coiled tube. This is the longest part of the alimentary canal. The human intestine, when straightened out, measures nine yards in length.

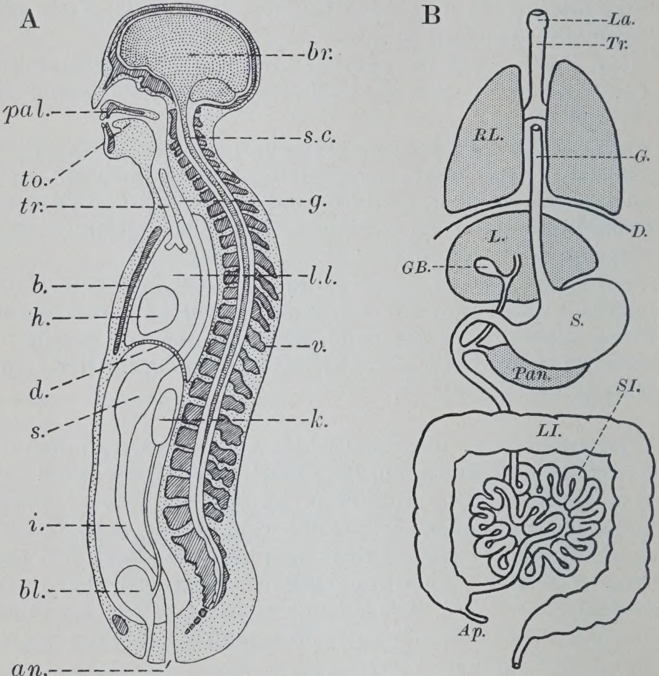

Fig. 3. *Diagrams of the principal internal organs of man.* A, side view; B, front view. In A, liver and pancreas are omitted; in B, heart and kidney are omitted. *an.* anus; *Ap.* appendix; *b.* breast bone; *bl.* bladder; *br.* brain; *D., d.* diaphragm; *G., g.* gullet; *GB.* gall bladder; *h.* heart; *i.* intestine; *k.* kidney; *L.* liver; *La.* larynx (Adam's apple); *LI.* large intestine; *l.l.* left lung; *pal.* palate; *Pan.* pancreas; *RL.* right lung; *S., s.* stomach; *s.c.* spinal cord; *SI.* small intestine; *to.* tongue; *Tr., tr.* trachea (windpipe); *v.* vertebrae.

The food is forced along the alimentary canal by its wall becoming pinched and these pinches passing along the canal away from the mouth end. The process is called *peristalsis* (Exp. 5). In the same way you could force water along a rubber tube by pinching it and sliding your fingers along. Those parts of the food which cannot be digested are passed out as *faeces* through the *anus*.

ENZYMES. The substances in solution which bring about digestion are known as *enzymes* (or ferments). Enzymes belong to a class of substances which the chemist calls *catalysts*. The peculiarity of catalysts is that they cause chemical substances to react together which would not otherwise do so or would only do so extremely slowly. For example, oxygen and hydrogen mixed together do not combine. But if they are mixed in the presence of platinum in a very finely divided state known as platinum black, then they combine to form water. Platinum black is a catalyst. Enzymes are peculiar catalysts formed by living matter. For instance, an enzyme called *ptyalin* is in solution in the saliva in the mouth. It causes *starch* in food to change to *sugar* (Exp. 6). Another enzyme is *pepsin* in the gastric juice. This breaks down the *protein* molecules.

Here we see the first of the *peculiarities of enzymes*: (1) each of them does just one thing. Ptyalin acts on starch alone among the food substances. Pepsin works on proteins only. Two other specialities of enzymes are that (2) they act best at a certain temperature, and that (3) they are destroyed by heat (Exp. 7). Again, (4) very small quantities of enzymes cause large amounts of chemical change. Pepsin will digest half a million times its own weight of protein. Yet another peculiarity is that (5) a certain definite degree of acidity or alkalinity of the solution is necessary for each different enzyme. Saliva is alkaline and ptyalin acts best in an alkaline solution (Exp. 8). The stomach produces hydrochloric acid and pepsin works best in an acid liquid (Exp. 9).

RESULTS OF DIGESTION. Digestion is not finished in the mouth and stomach. The food passes on into the intestine for further treatment. It has to be made soluble in water. Only after that will it be absorbed (taken in) through the intestine walls into the blood.

*Starch*, as you know, is turned into sugar by the saliva, and in addition we eat sugar itself. This sugar, which we put in tea, is called by the chemist *cane-sugar*. It is only one of various sugars. But cane-sugar, although soluble in water, cannot pass through the wall of the intestine into the blood. Before this can happen it must be changed by another enzyme into a simpler sugar, *glucose*.[1] The glucose in solution in water is then absorbed through the intestine walls into the blood. The sugar into which starch is finally turned before absorption through the wall of the intestine is also glucose.

The digestion of *proteins* begins in the stomach, where pepsin acts on them. It is finished in the intestine. For this purpose an enzyme called *trypsin* is formed in the *pancreas* (Fig. 3, B), an organ which you can see in the dissected frog. In solution trypsin flows from the pancreas into the intestine, and the proteins are again attacked. Trypsin acts only in a neutral liquid. The breakdown of proteins is finished in the intestine by a third enzyme which finally turns these very complicated molecules into much simpler ones known as *amino-acids*. Like glucose, the amino-acids go through the intestine wall into the blood stream in solution in water. *Fats*, too, are digested by yet another special enzyme.

FATE OF DIGESTED FOOD. The digested food is carried away from the intestine by the blood. It goes first to the *liver*. Here it undergoes further chemical changes, and then it is dispatched in the blood all over the body. When it has arrived at its destination in the living flesh, nearly all of the food is used for *energy liberation*. The greater part of the end-products of digestion of the three chief classes of foods, carbohydrates, fats and proteins, shares this fate.

We can compare the living organism to a machine. The portion of the food used for liberating energy is the fuel of the machine. But the working parts of the machine must be constructed. So, in a growing animal or plant, part of the food, a much smaller part than that used for fuel, is employed for *growth.* Amino-acid molecules from the digested food are combined together again to form protein molecules, which are an essential part of living matter. Glucose, fats and salts are likewise needed for growth. Notice, however, the enormous difference between the living machine and a dead one. This latter is constructed by adding part to part. A crystal, too, grows by fresh molecules attaching themselves in regular arrangement outside those there already. But living substance grows by internal additions and rearrangement.

---

[1] The formula of cane-sugar is $C_{12}H_{22}O_{11}$. That of glucose is $C_6H_{12}O_6$.

Now, a machine gradually wears out. So also does living material. In it there is a continual *wear,* a breakdown of complex molecules of proteins and other substances. These have all the time to be replaced. So even in an animal that is no longer growing, part of the food is always used for repair of wear and tear. The great biologist, Thomas Henry Huxley, compared living matter to a whirlpool. Energy and matter are continually streaming in and streaming out, but for a time the form remains the same.

In addition to the absorbed food used for energy release, for growth and for repair, part of the carbohydrate and fat is *stored up as a reserve.* Glucose is turned into a form of starch called *glycogen* and stored in liver and muscles. *Fat* is stored under the skin in ourselves, and in the body cavity of the frog (see dissection, Exp. 4).

SUMMARY. Digestion of food changes proteins into amino-acids, and starch and cane-sugar into glucose. Amino-acids, glucose, fats, salts and water are absorbed from the gut into the blood. This absorbed food is then used (1) for energy liberation, (2) to build up living substance during growth, (3) to repair breakdown of living substance, and (4) some fat and glycogen is stored for further use.

## PRACTICAL WORK

Careful drawings must be made of everything that is examined.

*Exp.* 1. Examine the "sleep-movements" of flowers such as the daisy or tulip.

*Exp.* 2. Put a clover plant into darkness. After an hour or so the leaves will have folded down.

*Exp.* 3. A thermometer shows that the temperature of sprouting seeds is higher than that of the surroundings.

*Exp.* 4. A frog, dissected to show the alimentary canal, should be exhibited to the class.

*Exp.* 5. Peristalsis can be seen very clearly through the transparent body wall of the larva of a fly. Purchase blow-fly larvae from a fish-bait shop. Hold a larva still in a compressorium and examine it with a low power of the microscope (one-inch objective).

*Exp.* 6. Prepare a solution of starch by making a paste with cold water and pouring hot water on to this. Take some in a test-tube and add a drop of a solution of iodine in potassium iodide. A blue colour appears. This is a test for starch. Add some of your own saliva. The blue colour gradually disappears as the starch is digested to sugar by the ptyalin in the saliva.

*Exp.* 7. Repeat *Exp.* 6, but after adding the saliva bring the mixed solution to the boil and cool it again.

*Exp.* 8. Test some saliva with litmus.

*Exp.* 9. Demonstration of the action of pepsin. Scrapings from the wall of a frog's stomach are mixed with water. Hydrochloric acid (0·5 per cent.) is added and then small cubes of the white of a hard-boiled egg are put into the solution. A crystal of thymol is added to prevent putrefaction. The test-tube is put in a warm place. Next day the egg-white (protein) is partly digested. It can further be shown that no digestion takes place if the solution is neutral or alkaline, or if it has previously been boiled.

## *CHAPTER II*

# RESPIRATION

Energy liberation. How is the energy of food set free in the body? How is the potential energy which is bound up in the products of digestion liberated to do work, for example by causing muscles to contract?

Some chemical compounds contain a lot of energy, others contain less. When compounds of the first kind change into compounds of the second kind, energy is freed. This is what happens when petrol combines with oxygen in the motor-car cylinder. The spark merely heats the gases to a temperature at which they will combine. The gases resulting from the combination of oxygen with petrol vapour contain less energy than the latter did. The energy has been freed, and it does work in moving the piston.

Muscular work. For the working of muscles the energy source is *a compound of phosphoric acid with a base.* This compound is contained in the muscles. As energy is required for a muscle to contract and so to do work, the compound in question is split into phosphoric acid and the base. The molecules of phosphoric acid and of the base have a smaller energy content than the molecules of the original compound. Thus, in the chemical change, energy is set free.

After the chemical change just described has been completed, the phosphoric acid and the base re-combine again to form the original compound. But, as you now know, the latter contains more energy than its constituents do. Therefore, for its re-formation, energy must be supplied from somewhere. The necessary energy is furnished by a second chemical reaction in the muscle, namely, by the change of the carbohydrate *glycogen* into *lactic acid.*

You will remember that the blood brings the carbohydrate *glucose* to the muscles, where it is changed into glycogen and stored in this form (p. 9). Glycogen has a greater energy content than lactic acid. Therefore, in the change from the former into the latter, energy is set free. This energy is used to re-combine phosphoric acid with the base spoken of above.

These energy changes may be compared with those which take place in an electric accumulator. By a chemical reaction energy is freed, appearing in the case of the accumulator as electrical energy. For the run-down accumulator to be re-charged, energy must be supplied. A current is sent through the accumulator. The electrical energy thus supplied is used to re-combine the chemical compounds in the accumulator. Muscle is re-charged with chemical energy, not by an electric current, but by energy derived from another chemical reaction, namely the change of glycogen into lactic acid.

RESPIRATION. This is not yet the whole story of that complicated machine, a muscle. After the glycogen has turned into lactic acid, the latter is not thrown away: at least, all of it is not thrown away. Part (four-fifths) of the lactic acid is changed back once more into glycogen. Obviously, energy is needed for this to happen, since glycogen contains more energy than lactic acid. This time the energy is provided by the *oxidation* of part (one-fifth) of the lactic acid. By combining with oxygen, one-fifth of the lactic acid is oxidized to *carbon dioxide* and *water*. Energy liberated in this oxidation brings about the transformation of the remainder of the lactic acid into glycogen once more.

Oxygen, then, is necessary for the working of the body. It is needed to oxidize lactic acid. We obtain the oxygen by *breathing*. Air contains 21 per cent. of oxygen. We take air into our *lungs* (Fig. 3), and there some of the oxygen goes into the blood. The blood stream carries this oxygen to all parts of the body, where it oxidizes various substances, including lactic acid. The resulting carbon dioxide comes back in solution in the blood to the lungs. We breathe out this carbon dioxide (Exp. 1). Our outgoing breath has in it only 17 per cent. instead of 21 per cent. of oxygen, but it contains 3 per cent. of carbon dioxide in place of 0·03 per cent. which is normally present in air.

This oxidation of lactic acid in the muscles, and the oxidation of other chemical compounds in the body, is known as *respiration.* The word "respiration" means not only the oxidations just spoken of. It includes also breathing movements, the exchange of oxygen and carbon dioxide between air and blood in the lungs, and the transport of these gases round the body by the blood stream.

A man, a dog or a bird makes breathing movements to take in oxygen to the lungs and get rid of the carbon dioxide. But there are other animals which do this without such complications. A worm, for instance, exchanges these gases with the air all over the surface of its body (Exp. 2). So, too, a plant (Exp. 3). Fishes have to use oxygen which is dissolved in the water around them. They take it into their blood at the gills.

ENGINES. Muscle has sometimes been compared with a steam engine. In both, energy is liberated to do work, and in both this energy liberation involves an oxidation. In the engine coal is burnt, that is to say, carbon is oxidized to carbon dioxide. In the body lactic acid is oxidized, with a resulting production of carbon dioxide. But in the engine the chemical energy is transformed into *heat*, which then changes water into steam. In the animal body *chemical energy* is used directly to "re-charge the accumulator", turning lactic acid into glycogen so that this glycogen may later on break down again to lactic acid and furnish the energy to re-form the energy-containing phosphorus compound.

It is true that when the phosphorus compound breaks down into phosphoric acid and the base, besides the energy liberated for muscular work, some energy appears as heat. It is true also that when glycogen changes to lactic acid, in addition to the chemical energy freed to re-form the phosphorus compound, some energy appears as heat. And likewise, when lactic acid is oxidized, heat is liberated in addition to the chemical energy which goes to convert the remainder of the lactic acid back into glycogen. For this reason our bodies are warm. The human body, however, is not a heat engine like the locomotive. Heat energy makes the locomotive work. But chemical energy makes our muscles work, while at the same time some heat is incidentally produced.

FATIGUE. You know now that lactic acid is continually being produced in muscles which are working. By oxidation of part of this lactic acid the remainder is re-formed into glycogen. But, if insufficient oxygen gets to the muscles, the lactic acid will accumulate.

If it does accumulate, the muscles work less and less well. They become *fatigued.* It is clear, then, that the blood circulation must bring enough oxygen to the muscles if there is to be no fatigue. Now, there is a limit to the amount of oxygen which the blood can ferry. If you ask too much of your muscles they do become fatigued. This is the result when you take too violent exercise. Lactic acid piles up in the muscles and fatigue sets in. The muscles, however, can go on working up to a point, even if the blood cannot supply all their oxygen requirements. This is what happens if you run a race. After the race is over you pant. In panting you are supplying more than the usual quantity of oxygen to your blood. This extra oxygen goes round the body and gradually oxidizes the surplus lactic acid. When all this accumulated lactic acid is gone you will breathe normally again.

CONSERVATION OF ENERGY. The energy liberated in the body is used in part, as you have seen, to do work, that is, to move, to grow, to repair. And in addition, part of the energy appears as heat. Now, we know from physics that energy cannot be destroyed. When one kind of energy changes into another kind none is lost and none is gained. This is what is called the conservation of energy. A certain mass of chemical substances which combine and liberate energy always set free a very definite quantity of energy which will do a definite amount of work—no more, no less. Or a certain definite amount of energy may be freed as heat. No energy is gained or lost.

Last century an extremely important discovery was made about the working of our bodies. It was found that just as the conservation of energy is true for chemical reactions and for machines, so, too, it holds for living things. This is how it was first found out.

A dog was kept in a special kind of cage. Its food was all weighed. An equal amount of the same food was burnt, all of its potential energy being thus turned into heat energy. This heat was measured. Thus the amount of energy was known which went into the dog in its food. For exercise the dog turned a sort of treadmill, so that the muscular work it did could be measured. This was done by putting a brake on the wheel so that all the energy was turned into heat, which was then measured. Energy set free as heat by the dog's body was absorbed and measured, and unused potential energy of the food was found by burning the dog's faeces. The amount of energy going into and coming out from the dog's body was thus known. So a balance sheet was made up. The result of the experiment was to prove that the potential energy of the food, minus that of the faeces, is equal to the mechanical energy produced plus the heat formed in the dog's body. And this is true, too, of ourselves and of all living organisms. The conservation of energy holds. No energy is produced in life from any mysterious source.

## PRACTICAL WORK

*Exp.* 1. Blow through lime water. The carbon dioxide in the breath turns calcium hydroxide into calcium carbonate, which is visible as a milky precipitate.

*Exp.* 2. See Fig. 4. The carbon dioxide given off by the worm is absorbed by the potash in *c*. Owing to this, and to the absorption of oxygen by the worm, the pressure of gas falls in *a*, and consequently the coloured liquid rises in the manometer *d*. This measures the oxygen consumption. The external vessel of water, *f*, keeps the temperature constant. It is necessary because the rate of respiration, like that of all chemical processes, varies with temperature. This can easily be shown by repeating the experiment at different temperatures.

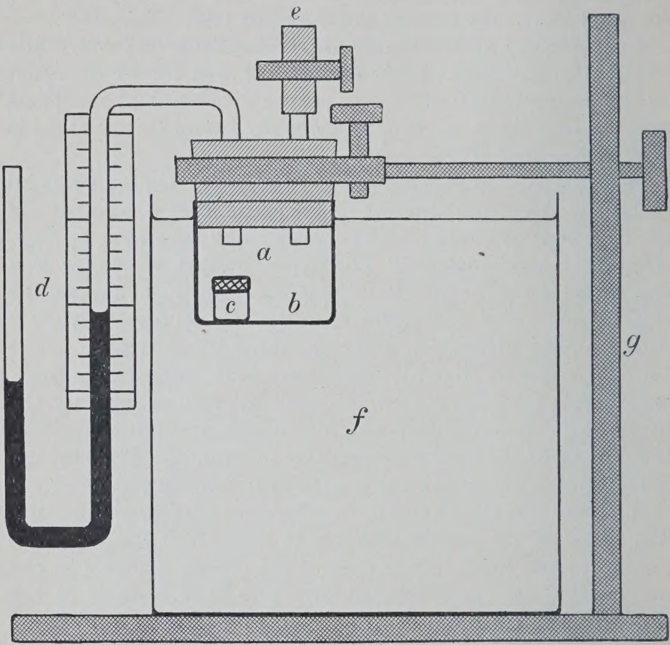

Fig. 4. *Apparatus for measuring the oxygen consumption of a worm*, or other small organism (*Exp*. 2). *a*, large specimen tube cut short and fitted with a rubber bung. A worm is put in this tube at *b*; *c*, small specimen tube cut short, containing cotton wool soaked in 5 per cent. potash solution and closed by gauze held on with a rubber band; *d*, manometer with paper scale; *e*, glass tube closed by screw clip on pressure tubing; *f*, water in battery jar; *g*, retort stand.

*Exp*. 3. A taper is extinguished when plunged into a jar in the bottom of which seeds are sprouting.

## *CHAPTER III*

# BLOOD

THE nature of blood has been hinted at several times already. It is a liquid that circulates in channels, or *blood vessels*, round the body. The movement is caused by a rather complicated pump, the *heart*.

ARTERIES AND VEINS. From the heart the blood passes into large channels known as *arteries*. These branch and divide and divide again into smaller and smaller arteries, so that blood is driven by the heart to all parts of the body. Finally the branches become so small that they cannot be seen with the naked eye. These smallest channels are called *capillaries* (Fig. 5). They run through every corner of the body.

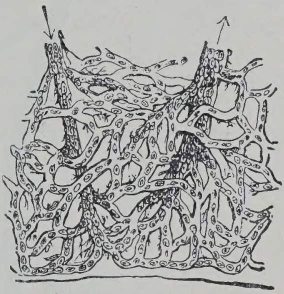

Fig. 5. *Blood capillaries*. The arrows show how blood arrives in a small artery, passes through a network of capillary blood vessels and leaves in a small vein. The round objects in the capillaries are blood corpuscles.

The capillaries not only branch many times but the branches join with one another so that a *network* of very small tubes is formed. As the blood stream passes through this capillary network in every part of the body, the capillaries run together to form bigger and bigger channels. Finally these vessels get so big that, like arteries, they are once more visible to the naked eye. These are the *veins*. They run back towards the heart. In this way the closed circuit of the blood stream is completed.

THE HEART. What is the exact course of the blood round the different parts of the body? Fig. 6 shows that

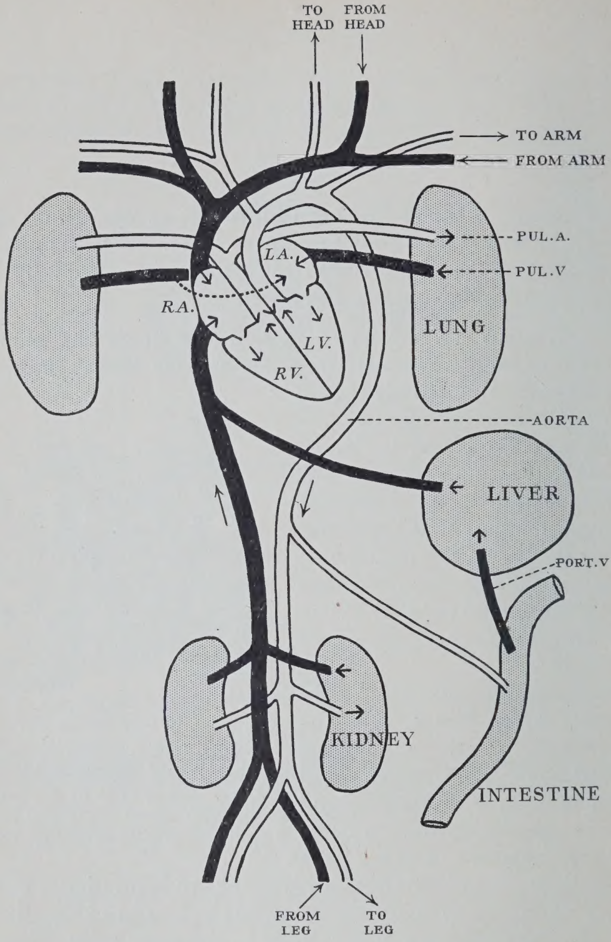
TO HEAD
FROM HEAD
TO ARM
FROM ARM
PUL.A.
PUL.V
L.A.
R.A.
L.V.
R.V.
LUNG
AORTA
LIVER
PORT.V
KIDNEY
INTESTINE
FROM LEG
TO LEG

Fig. 6. *Diagram of the human heart and blood vessels*, seen from in front. Veins are shown black, arteries white. The valves at the openings into and out of the ventricles are indicated. The course of the circulation is shown by arrows. ***LA.*** left auricle; ***LV.*** left ventricle; ***PORT.V.*** portal vein; ***PUL.A.*** pulmonary artery; ***PUL.V.*** pulmonary vein; ***RA.*** right auricle; ***RV.*** right ventricle.

the heart is made up of a right and left half. It really consists of two pumps, on the right- and left-hand sides, which have no communication with one another.

Blood flows into the heart from all over the body through the veins that lead into its right front part. This is called the *right auricle*. When it is full of blood it contracts. That is to say, its walls tighten like the rubber bulb of a motor horn squashed by the hand. This forces the blood that is in this right auricle into the next chamber, the *right ventricle*. Immediately this is full of blood it contracts in its turn. The result is that the blood from the right ventricle is forced into two arteries. These are called the *pulmonary arteries*, and they lead straight to the two lungs.

But here a question will at once be asked. When the auricle wall contracts, why does the blood in the auricle all go into the ventricle and none of it back again into the veins? When in turn the ventricle contracts, why does the blood go into the pulmonary arteries? Why does it not return into the auricle? The answer is that at the junction of veins with auricle, and of auricle with ventricle, there are *valves*. These are flaps which prevent the blood from going the wrong way. For example, when the auricle contracts, the flaps close the road back into the veins, but the valves at the entrance from auricle to ventricle allow the blood to go that way.

THE LUNGS. Blood from the right ventricle goes *via* the pulmonary arteries into the lungs. Each pulmonary artery divides and divides again into innumerable capillaries in the lung. The lungs consist of thousands of little air passages. The air we breathe in passes down the *trachea* (Fig. 3), or windpipe, into those air passages. The latter end in blind alleys, the *air sacs*. On all the walls of these air sacs are the capillary blood vessels. So the blood comes very close to the air. Here oxygen passes from the air into the blood, and carbon dioxide passes the other way. The value of having the immense number of blind alley air passages and innumerable capillaries is to have a huge total surface for the exchange of gases between blood and air.

From each lung the blood capillaries join together into a *pulmonary vein.* These two veins lead the blood away from the lungs, and pour it, charged with oxygen and minus its carbon dioxide, into the left front chamber of the heart, the *left auricle.* Each time this is full it contracts, driving its blood into the *left ventricle.* This in turn contracts, and, since, as before, valves will not let the blood go back, the blood is forced out of the heart into a huge artery, the *aorta.* This blood, with its cargo of oxygen, goes all over the body. The aorta divides into smaller arteries, and these into capillaries in head, limbs, alimentary canal, and every part of ourselves.

A grown man has four litres of blood in his body. The heart normally pumps eight litres a minute into the aorta, and three or four times as much when it is beating fast during exercise.

BLOOD CIRCULATION. It is plain that the heart is a double pump. The right and left sides are separate. Yet the two auricles contract at the same time. They do this seventy or eighty times per minute. And immediately afterwards the two ventricles contract. This is the *heart beat.* The ventricles have much thicker walls than the auricles, for they have more work to do in forcing blood through the arteries into the capillaries.

Each time the ventricles force blood into the arteries the pressure causes the latter to swell slightly. An instant afterwards the artery walls, which are elastic, return to their former size. This swelling with each heart beat passes quickly as a wave along each artery away from the heart. It is the *pulse.* It is necessary for the artery walls to be elastic in order to press upon the blood and force it along.

This extraordinary pump, the heart, works continuously without a stop from long before our birth until death. Its only rest is in between each beat and the next one. William

Harvey (Fig. 152), in the reign of James I, was the first person to discover how blood circulates and how the heart works.

Look now through the microscope at blood flowing through the transparent web of the frog's foot (Exp. 1). You will see the pulse in the arteries. Blood flows rhythmically and quickly here, more slowly in the capillaries, and there is again a quicker but even flow in the veins. You see small bodies floating in the blood. These are *corpuscles* (Fig. 5). Each is 0·02 millimetre in diameter. The flow is slower in the capillaries because their total cross-section is greater than that of arteries or of veins. In the same way water flows more slowly in a lake than in the rivers that lead into and out of it. The blood flow appears very swift, but of course the capillary is magnified by the microscope. Actually, in ourselves, blood flows only at half a millimetre per second through the capillaries. But it leaves the heart at fifty centimetres a second.

HAEMOGLOBIN. What is the necessity for this never-ceasing blood stream round the body? There are several reasons for it. Two of the reasons you know already. In the first place, blood takes the *oxygen* which is necessary for respiration from the lungs to the living substance in all parts of the body, and it removes unwanted *carbon dioxide* in solution back again to the lungs to be got rid of.

But why is blood *red*? The reason is this. An enormous amount of energy is required for life processes. You know how the energy is liberated, and blood has to carry sufficient oxygen for the process. Yet if blood were merely water, the heart would have to beat forty times as fast as it does in order to supply the body with all the oxygen it requires. Or there would have to be forty times as much blood as actually is contained in our blood vessels. This would mean that the heart, arteries and veins would have to be impossibly large.

So the human body adopts another method. A red-coloured protein, called *haemoglobin*, is present in the blood.

It is a protein containing iron. Now, haemoglobin has the property of taking up much more oxygen than could be dissolved in water. Actually in human blood forty times more oxygen is taken in from the lungs in this way than would otherwise be possible. Wherever oxygen is needed for energy liberation it is abstracted from the haemoglobin through the thin walls of the capillaries (Exp. 2). The haemoglobin in blood is contained in the *corpuscles* which you saw in the blood vessels of the frog's foot. The colourless liquid part of the blood, in which the corpuscles float, is called *plasma*.

TRANSPORT OF FOOD. The first use of blood to the body is the transport of oxygen and carbon dioxide. The second is the carriage of digested food from the walls of the intestine to the liver, and, from the liver on, all over the body. From the intestine glucose, amino-acids and other products of digestion diffuse into capillaries in the intestine wall. These capillaries lead into a vein going to the liver. This is called the *portal vein* (Fig. 6). From the liver the foods pass in the blood stream to the heart and then all over the body, where they diffuse out of capillaries into the living substance. But there are yet other functions of blood.

WASTE MATTER. You know that *carbon dioxide* is carried by the blood in solution from all parts of the body to the lungs. It is a waste product. If it were not got rid of it would quickly upset the working of the living machine. But carbon dioxide is not the only harmful by-product of the chemical changes that go on in the living body. Carbon dioxide is the waste from respiration. But you have learnt already that not only is fuel (the absorbed food) being used all the time to liberate energy, but in addition the machine itself is continuously wearing and being replaced. This wear means the breakdown of protein molecules, which are the chief constituent of the living substance. Proteins contain nitrogen. They break down into simpler chemical compounds containing nitrogen, and finally into *urea*.[1]

It is the *kidneys* which have the work of turning urea out of the body. The blood stream goes through the kidneys (Fig. 6). Urea here passes out of the blood dissolved in water. The solution of urea and other waste substances in water which leaves the kidneys is called *urine*. It is temporarily stored in the *bladder* (Fig. 3, A) and then goes out of the body. This process of getting rid of urea and other harmful waste stuffs is known as *excretion*. In addition, the kidneys pass surplus water out.

HEAT DISTRIBUTION. Our bodies are warm. How they are kept at exactly the same temperature, to within a degree, you will learn later on. But you know already that the energy liberated in the body appears partly as heat. Now, this heat is not formed in equal amounts all over the body. A lot of it appears in the muscles and in the liver. It is the blood stream that carries the heat round and distributes it equally all over the body. The blood is thus like a hot-water circulation in a centrally heated house.

COMMUNICATION. Again, blood is one of the two ways in which different parts of the body communicate with one another, so that all the parts shall work in harmony. The other way is through nerves. To take one example of communication by the blood: the pancreas only produces trypsin when food is in the intestine to be digested. How does it know this? The food on arrival in the intestine causes a chemical substance to pass from the intestine wall into the blood. When this chemical arrives *via* the blood stream at the pancreas, it gives the signal for trypsin to be let loose. In this way the pancreas works just at the right moment. Such chemical messengers are called *hormones*.

DEFENCE. Finally, there is yet another function of blood which can only be mentioned now. Blood is one of the defences of the body. When we are vaccinated or inoculated against *diseases*, the defensive action of our blood is increased. You will hear more of this further on.

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[1] Urea has the formula $CO(NH_2)_2$.

Remember, too, that blood *clots* when a wound bleeds. This prevents loss of blood from a small wound.

CONTROL OF BLOOD FLOW. When we exert ourselves our hearts beat more rapidly. The quicker stream of blood supplies more oxygen as this is needed. In addition to this there is a way by which particular parts of the body get more blood when at any moment they need it.

Arteries can change their diameter: they can widen or narrow. Suppose your arm is working. It needs more oxygen and so more blood. The arteries and capillaries in the arm become wider and more blood gets there. At the same time arteries narrow in other parts of the body where there is a less pressing demand for blood. If you run, your legs get more blood and your stomach and intestine get less. But after a meal more blood is sent to the gut and less to the brain and surface of the body: consequently you may feel sleepy and even chilly.

## PRACTICAL WORK

*Exp.* 1. Demonstration under the microscope of the blood circulation through the web of a frog's foot. The frog should previously be anaesthetised by putting it for half an hour into a 2 per cent. solution of urethane in water.

*Exp.* 2. Haemoglobin is scarlet when charged with oxygen, purple when without oxygen. In the body the oxygen is given up to those parts of the living substance which lack oxygen. But haemoglobin will also give up oxygen to a reducing agent. A demonstration should be made as follows. A dilute solution of haemoglobin is made with a drop of blood from a pricked finger in a test-tube of water. On adding a very small quantity of powdered sodium hydrosulphite from the tip of a knife the scarlet colour changes to purple. On shaking up the solution with air the scarlet reappears.

# *CHAPTER IV*

# THE FROG

You have already seen a dissection of a frog. This showed you the alimentary canal, the liver, the heart, and the lungs. We are now going to study the frog in more detail. The reason for choosing the frog rather than another animal is that in the first place it is easy to get, and in the second its body is built on the same general lines as our own, although in many ways its structure is simpler. We shall study the frog both from the points of view of *anatomy* and of *physiology*. Anatomy is the science of the structure of animals and plants; physiology is the study of function, that is to say, the way in which the parts of the body work.

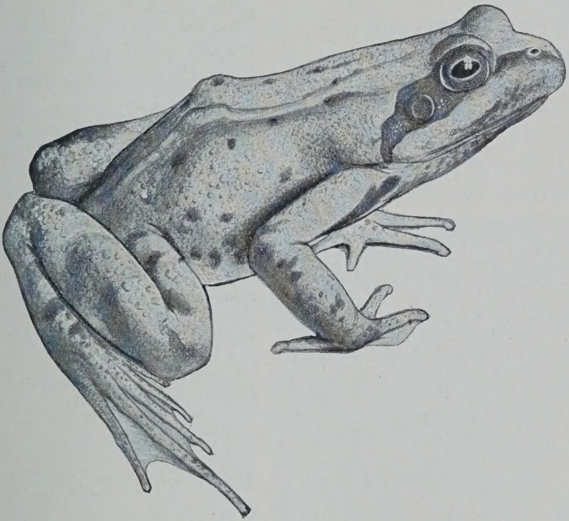

Fig. 7. *The frog.*

The frog (Fig. 7 and Exp. 1) has a head with a *mouth, nostrils* and *eyes*. Although there are no *ears* looking like our own, yet the frog has ears. The two rings on the dark patches behind the eyes correspond to our ear drums.

There are two pairs of *limbs*, of which the hind pair is much the larger. Their structure is specially adapted to jumping and swimming. The *webbed feet* help the latter. There is no tail, but the young stage of the frog, the *tadpole*, has a long tail, and so has the *newt* which is a near relation of the frog found in ponds.

SKIN. Unlike our own, the frog's skin is moist. Our skin is dry because its outer layers are dead. Since we have this dry, dead layer on the outside of our skin, our body does not lose much water by evaporation in dry air. The frog is not protected in this way, and as a result it can only live in damp places.

You have heard already how oxygen and carbon dioxide are exchanged between blood and air in the lungs. For this exchange to take place (by gas diffusion) a wet living surface is necessary, for the blood capillaries must come very near to the surface, and if this surface dried up these blood vessels would be injured. Consequently the gas exchange in ourselves takes place in lungs inside the body, protected from the risk of drying up. The frog, too, has lungs, but it breathes not only through these lungs but to a large extent through its moist living skin, just like an earthworm.

COLOUR CHANGE. The frog's skin can change colour. It may become a light yellowish green or a darker brownish green. The change depends on outside conditions. A frog is light coloured in dry air, in bright light or when the temperature is high. The same animal goes dark in dampness, darkness or cold (Exp. 2).

THE MOUTH. If the mouth of a frog is opened widely the *tongue* is seen (Exp. 3). Unlike our own tongue, it is attached in front and the free end points backwards (Fig. 9,

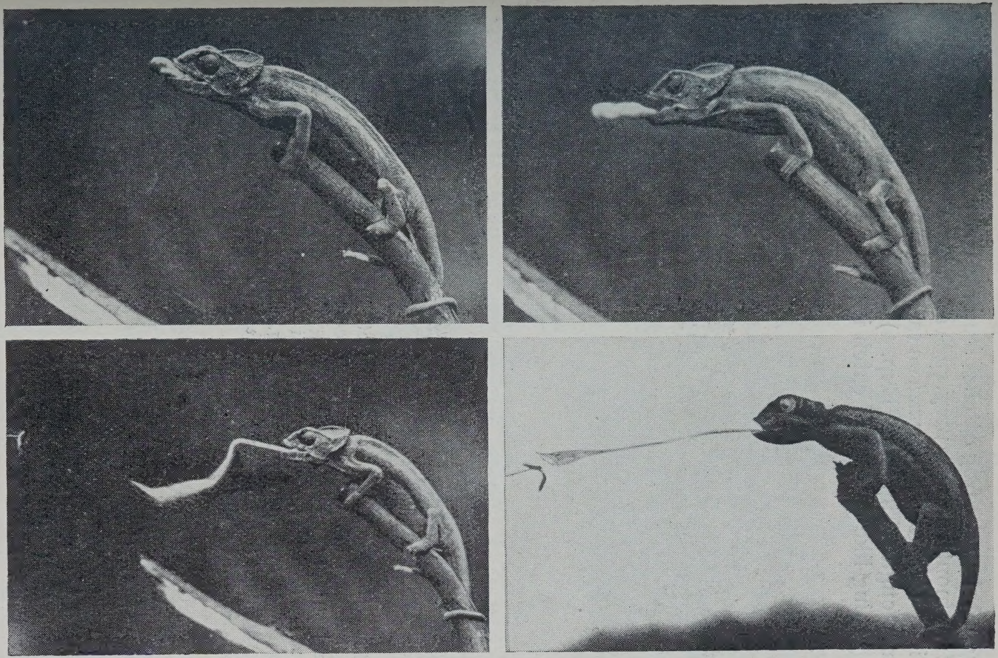

Fig. 8. *Chameleon feeding*. The reptile is darting out its long tongue to catch a small worm held out to it on a pin.

*tng.*). When the frog catches food the free end is thrown out of the mouth and the prey, such as an insect, is caught on the sticky tongue. The *chameleon* (a reptile) has an enormously long tongue (Fig. 8 and Exp. 4) which it can flick out with lightning-like speed and catch insects a long way off.

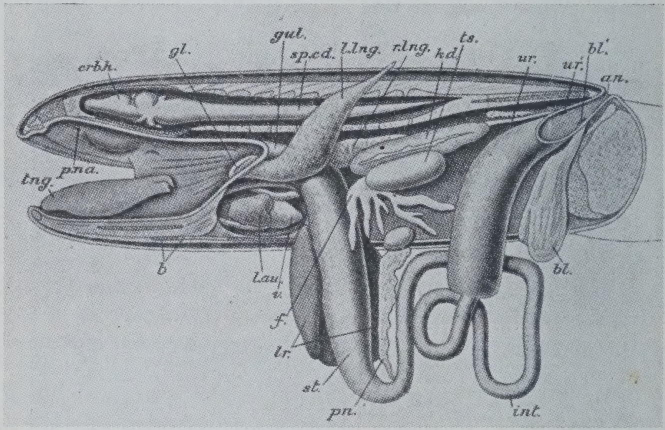

Fig. 9. *Dissection of frog*, from the left side. *an.* anus; *b.* breast bone; *bl.* bladder; *bl'.* its opening into end of intestine; *crb.h.* cerebral hemisphere; *f.* fat; *gl.* glottis; *gul.* gullet; *int.* intestine; *kd.* kidney; *l.au.* left auricle; *l.lng.* left lung; *lr.* liver; *pn.* pancreas; *p.na.* opening from nose into mouth cavity; *r.lng.* right lung; *sp.cd.* spinal cord; *st.* stomach; *tng.* tongue; *ts.* testis; *ur.* kidney duct; *ur'.* its opening into end of intestine; *v.* ventricle.

The frog swallows its food whole without chewing it up, passing it back into the *gullet* which leads to the stomach (Fig. 9). On the roof of the mouth is a pair of openings leading from the *nose*. In ourselves these are placed further back, behind the palate. Below the gullet is a slit-like opening, the *glottis*, leading to the windpipe or *trachea* which goes to the lungs. In man the *larynx* (Adam's apple), which is the organ of voice, is just below the glottis (Fig. 3, B, *La.*).

**Skeleton.** Look now at the skeleton of a frog (Fig. 10 and Exp. 5). It is made partly of *bone* and partly of a softer stuff called *cartilage*. The ends of the shoulder blades, for example, are composed of cartilage. The skeleton is made up of skull, backbone or spine, and of limbs, together with bones attaching the limbs to the body.

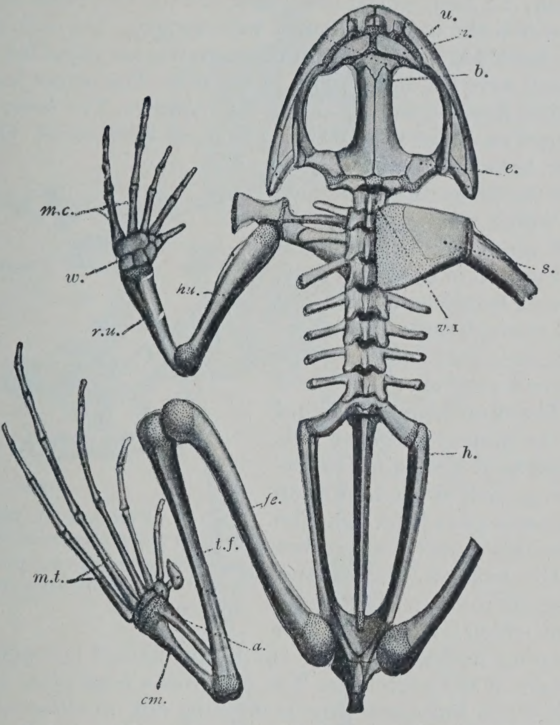

Fig. 10. *Skeleton of frog.* *a.*, *cm.* ankle bones; *b.* brain case; *e.* ear capsule; *fe.* femur; *h.* hip girdle; *hu.* humerus; *m.c.* metacarpals; *m.t.* metatarsals; *n.* nasal capsule; *r.u.* radio-ulna; *s.* shoulder blade; *t.f.* tibio-fibula; *u.* upper jaw; *v.*1, first vertebra; *w.* wrist bones.

We will take the *skull* first. In the middle is the *brain case*, a hollow box of bones enclosing and protecting the brain. In front of the brain case are the two *nasal capsules* in which the organs of smell were lodged. On each side of the back part of the brain case are the *ear capsules*, inside which were the inner parts of the ears. The *upper jaw* with *teeth* is fixed to the nasal and ear capsules. The *lower jaw* is hinged on either side to the back angle of the skull. On each side, between the upper jaw and the brain case, is a space in which was the *eye*. You will see a number of holes in the wall of the brain case. *Nerves* from the brain came out through these. One larger hole on either side is for the nerve to the eye.

The skull is hinged behind to the spine or *backbone*. This consists of nine joints or *vertebrae*, each of them built on the same plan (Fig. 11). The lower solid part of a vertebra is the *centrum*. Above this is an *arch* of bone. The *spinal cord*, which is the main nerve running backwards from the brain, passed through these arches of the vertebrae. The arch has a long piece of bone called the *transverse process* sticking out on either side.

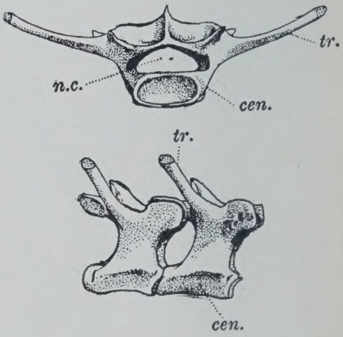

Fig. 11. *Vertebrae of frog*, seen from in front and from the right side. *cen.* centrum; *n.c.* position of spinal cord within arch; *tr.* transverse process.

If you look now at the way in which two vertebrae join one another you will see that there are ball and socket joints between the centra, and that projections from either side of the arches fit together. Thus the backbone is not quite rigid, but there is a little play between the vertebrae. Looking at the backbone from the side, you will notice spaces between the arches. Through these spaces nerves came out from the spinal cord. At the hind end of the

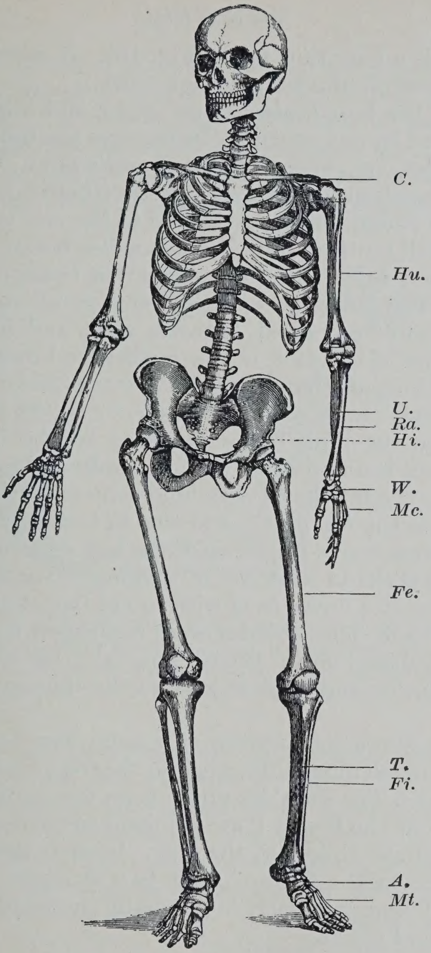
C.
Hu.
U.
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Fig. 12. *Human skeleton*. *A*. ankle bones; *C*. collar-bone (part of shoulder girdle); *Fe*. femur; *Fi*. fibula; *Hi*. hip girdle; *Hu*. humerus; *Mc*. metacarpals; *Mt*. metatarsals; *Ra*. radius; *T*. tibia; *U*. ulna; *W*. wrist bones.

backbone is a long thin bone (Fig. 10). It corresponds to the tail skeleton of a tadpole or a newt.

Each of the four *limbs* has an upper and a lower main bone jointed to one another. In the arm the upper bone is the *humerus*, the lower bone the *radio-ulna*. The corresponding bones in the leg are the *femur* (thigh bone) and the *tibio-fibula* (shank bone). Attached to the end of the lower bone of each limb is a number of smaller bones. These are the *wrist* and *ankle* bones. Then come the bones of the hand and foot. The inner row of these corresponds to the bones of the palm of our hand, between wrist and fingers, and to the bones of our foot, between ankle and toes. They are called *metacarpals* (hand) and *metatarsals* (foot). The outer jointed bones are those of the *digits*, or *fingers* and *toes*.

How are the limb bones attached to the body? The arrangement is different for the fore-limbs and for the hind-limbs. The thigh bone of each hind-limb is jointed to what is known as the *hip girdle*, and this in turn is attached to the large transverse processes of the last vertebra. But the front-limb skeleton is not directly connected with the backbone. There is a *breast bone* with broad flat *shoulder blades* attached to it. These blades were connected to the backbone by muscles only. Breast bone and blades form the *shoulder girdle*, and to it is jointed the humerus of either side.

Fig. 12 shows the *skeleton of a man*. The brain case is relatively much more bulky than in the frog, for the brain is much bigger. The shoulder girdle is on the same plan as in the frog, but the breast bone is joined to the backbone by *ribs*, which are absent in the frog. In man there is not a single bone in the forearm, but two separate bones, the *radius* and *ulna*. Similarly in the shank there are two bones, the *tibia* and *fibula*.

MUSCLES. If you skin a frog which has been killed you will see the muscles of the body (Exp. 6). The function of muscles is, of course, to move the various parts of the body. The action of a muscle will be understood by considering the *biceps* of man (Fig. 13). The muscle has a thick middle part and narrow ends. The ends or *tendons*[1] are attached to bones, the upper tendons to the shoulder girdle, the lower tendon to the radius. A muscle does work by "contracting", though this word is unfortunate, because the muscle really becomes shorter and thicker but does not change in volume. Fig. 13 shows you that when the biceps contracts, it causes the radius bone to move as a *lever*.

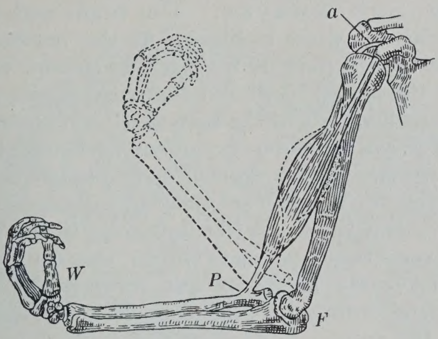

Fig. 13. *Action of the biceps muscle.* The muscle is attached by two tendons to the shoulder girdle at *a*, and by one tendon to the radius at *P*. When the muscle contracts, the lever (radius and ulna) is moved up on the fulcrum *F* (elbow), lifting the weight *W* (hand).

The various muscles in the body are either (1) attached like this to bones which they move as levers, or (2) they are attached by their ends to other muscles. Examples of the second kind are muscles which you see making up the wall of the belly or *abdomen* of the frog, muscles which cause peristalsis (p. 7) in the alimentary canal, and muscles of the heart.

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[1] Meat consists of muscle, sinew is tendon and gristle is cartilage.

FUNCTIONS OF THE SKELETON. It is now clear that the skeleton has several different functions. In the first place it makes the body to a certain extent *rigid.* Secondly the brain case and arches of the vertebrae *protect* the brain and spinal cord. And thirdly the bones of the limbs and the lower jaw are moved by muscles as *levers.*

BRAIN AND NERVES. The brain and nerves together make up what is known as the nervous system. There is a *central* part of the *nervous system,* namely the brain and the spinal cord, and there are *nerves* which connect the various parts of the body with the central nervous system. Pairs of large nerves, one on each side, branch out from the *spinal cord* through the spaces between the arches of the vertebrae. You can see these in a dissection (Exp. 7). And nerves join the brain through holes in the brain case.

The nerves take messages in to the central nervous system and carry messages out from it. The *incoming messages* come from *sense organs,* such as eye, nose and ear, by which the animal gets knowledge of what is happening in the outside world. Nerves also carry messages inward from the *skin* as to touch and temperature changes, and from the *tongue* concerning taste. Further, they convey information to the brain as to the amount of contraction of the various *muscles* which are working. *Outgoing messages* from the central nervous system through the nerves give commands to the muscles to contract as required. The fact that a nerve does carry such a message to a muscle can be shown by an experiment with a nerve and muscle of the frog (Exp. 8). You will hear more of the action of sense organs, brain and nerves in a later chapter (Chap. XVII).

Fig. 14 shows the *brains of a frog and of man.* At first sight they appear quite unlike, but really they are constructed on the same plan. The chief difference is the enormous development in man of the front part of the brain. This region is called the *cerebral hemispheres.* In the frog's brain you will see that this part is quite small.

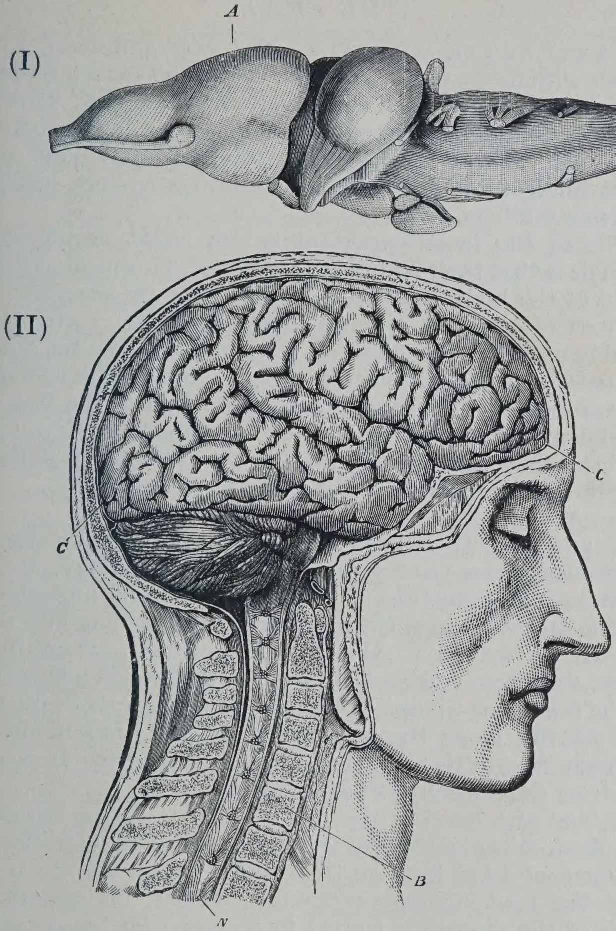

Fig. 14. *Brains of a frog* (I) *and of man* (II). The front of the frog's brain is on the left, and the beginning of the spinal cord on the right. *A* is the part corresponding to the left cerebral hemisphere of man. In the human brain, *C*, *C* is the right cerebral hemisphere, *N* is the spinal cord; *B* is a vertebra.

VERTEBRATE ANIMALS. The frog and man, together with fishes, reptiles (like the lizard and snake), birds, dogs, horses, etc., are all called vertebrate animals. However different they may appear, they are all built on the same plan. There are numerous other animals built on quite different lines. Such are insects, worms, oysters, snails, and many others.

One of the most important points about vertebrate animals is that their bodies are *segmented*. This means that parts of the body built on a certain plan are repeated a number of times in a series. Thus there are vertebrae coming one after the other, all more or less alike. So, too, the pairs of nerves coming off the spinal cord are repeated. If you look at the muscle forming the wall of the frog's abdomen you will see that it also is segmented (Exp. 6). And there are two pairs of limbs, in which the bones in the fore-limb correspond with the bones in the hind-limb.

VISCERA. The alimentary canal, together with other internal organs or viscera, such as heart, liver, kidneys, etc., lie in the *body cavity* (Fig. 9 and Exp. 9). In front, protected by the breast bone, is the *heart* with veins leading into it, and arteries leaving it. On either side of the heart are the *lungs*, each receiving air from the mouth through a branch of the *trachea* or windpipe. The air passes inwards through the nostrils, along the passages from nose into mouth, through the glottis and finally down the trachea. It goes out from the lungs by the same path.

Behind the heart is the *liver*. To this, as you know, the food, absorbed from the intestine after digestion, is first conducted through the portal vein (p. 22). In the liver the food undergoes certain changes, for instance some of the glucose is turned to glycogen for temporary storage.

But the liver has other functions. It produces *bile*. This greenish solution is stored for the time being in the *gall bladder* and then passes into the intestine. Bile contains certain waste products (excretions) which the body is getting rid of, and it also contains chemical substances which help in digestion.

Blood vessels. In a dissection of a frog you can see the course of the main blood vessels (Fig. 15). From the intestine blood is taken to the liver in the (hepatic) *portal vein*. The digested food absorbed through the intestine walls moves off in this vein to the liver. Leaving the liver again, this blood joins the main vein bringing blood from the back part of the body to the heart, the *posterior vena cava*. Blood from the front part of the body arrives through various branch veins into an *anterior vena cava* on each side of the body. These three veins, two anterior and one posterior venae cavae, pour their blood into the *right auricle*, whence it is passed into the *ventricle*.[1] Likewise in man you will remember that blood from the body arrives at the right auricle.

Blood then leaves the ventricle through two *pulmonary arteries* to go to the lungs. These arteries have big branches to the *skin*, for in the frog gas exchange between blood and air takes place at the skin as well as in the lungs. From the lungs blood moves back through *pulmonary veins* to the *left auricle*, and then into the ventricle.

Finally the blood leaves the ventricle to go all round the body. In man there is one *aorta*, curving round to the left side of the heart (Fig. 6). In the frog the aorta divides into two, one on each side. Branches come out from the aortae, taking blood to the head, before the aortae curve round on either side of the heart. The left and right aortae join behind the heart to form the *dorsal aorta*. This runs back at the top of the body cavity, above the posterior vena cava. Its branches supply blood to all parts of the body behind the heart.

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[1] The ventricle of the frog's heart is not divided into right and left halves as it is in man. Consequently the frog's heart is a less efficient organ.

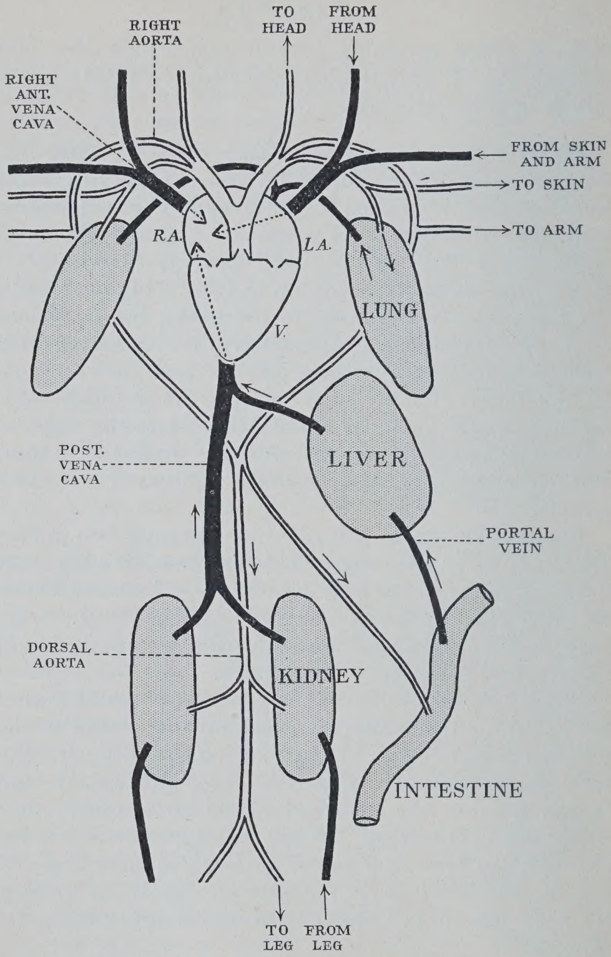
RIGHT AORTA
TO HEAD
FROM HEAD
RIGHT ANT. VENA CAVA
FROM SKIN AND ARM
TO SKIN
TO ARM
RA.
LA.
LUNG
V.
LIVER
POST. VENA CAVA
PORTAL VEIN
DORSAL AORTA
KIDNEY
INTESTINE
TO LEG
FROM LEG

Fig. 15. *Diagram of the principal blood vessels of the frog*, seen from below. Veins are shown in black, arteries in white. The valves at the openings into and out of the ventricle are indicated. *LA*. left auricle; *RA*. right auricle; *V*. ventricle.

REPRODUCTIVE AND EXCRETORY ORGANS. If the dissected frog is a *female*, the *ovaries* which produce the black eggs can be seen in the body cavity. The eggs, when ripe, come loose from the ovaries into the body cavity, and then they enter the open inner ends of two tubes called *oviducts*. These tubes are white and coiled. They lead into the hind part of the alimentary canal, just before its opening to the exterior. While the eggs are passing along the oviducts they become coated with jelly.

On the roof of the body cavity are the two red *kidneys* (Fig. 9). Dorsal aorta and posterior vena cava lie between them (Fig. 15). As you know, the kidneys take urea and surplus water from the blood (p. 23). These excretions are then passed down two tubes, the *kidney ducts* (Fig. 9), again into the hind part of the alimentary canal. Into this there also opens the *bladder*. Urine is temporarily stored here.

If the frog is a *male*, the kidneys are the same, but instead of ovaries there are two white *testes* in which the male reproductive product is prepared. This liquid, the *sperm*, passes out through the kidney ducts.

You will notice that in the frog faeces, urine, and eggs or sperm all go out to the exterior through the same opening.

## PRACTICAL WORK

*Exp.* 1. Examine a frog.

*Exp.* 2. Put frogs for a couple of hours in different conditions of humidity, light and temperature to see colour changes.

*Exp.* 3. Examine the mouth cavity of a frog.

*Exp.* 4. Chameleons can be purchased from dealers in London and kept alive in a vivarium in a warm and sunny situation. The method of feeding and the colour changes can be observed.

*Exp.* 5. Study the skeleton of a frog.

*Exp.* 6. Skin a frog to see the muscles.

*Exp.* 7. The spinal nerves and the brain in a dissected frog should be shown to the class.

*Exp.* 8. A muscle-nerve preparation should be made of the gastrocnemius muscle and sciatic nerve of a frog which has been beheaded by one stroke of a large pair of scissors. The effect of mechanically stimulating the nerve can be shown to the class.

*Exp.* 9. Demonstration of a dissected frog to show heart, main blood vessels, lungs, liver, testes or ovaries and oviduct, kidneys, kidney ducts, bladder, and cloaca.

## *CHAPTER V*

# PROTOPLASM AND CELLS

AMOEBA. So far we have been talking about man and about animals which, even if they are frogs, are not so very unlike man in structure. But now we are going to consider an animal which is as far away from man as an animal can be. It lives commonly in dirty water. It can only be seen under the microscope, and is called *Amoeba* (Fig. 16). When you examine it (Exp. 1), you will see a very small piece of semi-transparent jelly containing numerous granules. Actually it measures about half a millimetre across. It is made of a sort of half-liquid jelly, and if you look closely you will see that it moves.

Each individual *Amoeba* has an irregular and changing shape. As it moves along, a projection of the jelly protrudes. A high magnification with the microscope will show you that the substance of the *Amoeba* has numerous very small granules in it. As the projection, or *pseudopodium* (false foot) as it is called, pushes out from one side of the animal, the granules are seen to flow into it. The jelly-like substance of the *Amoeba*, then, is liquid in the middle.

If the *Amoeba*, in the course of its wandering in the water, meets a microscopic plant, a remarkable thing happens. It flows around the plant and the latter gets enclosed inside the *Amoeba*. The small plant is surrounded by a bubble of water inside the animal. It has been eaten. It is then slowly digested inside the bubble, or *food vacuole*. Digestive enzymes pass from the substance of the *Amoeba* into the bubble for this purpose. Later on, the indigestible remains of the food are pushed out of the *Amoeba*.

Thus you see that the *Amoeba* lives, but that it has an ever-changing *shape*. It *moves*, but it has no limbs. It *eats* and *digests*, but it has no mouth nor alimentary canal. And more than this, it has all the other special features of life. It *respires*. Dissolved oxygen from the water passes into

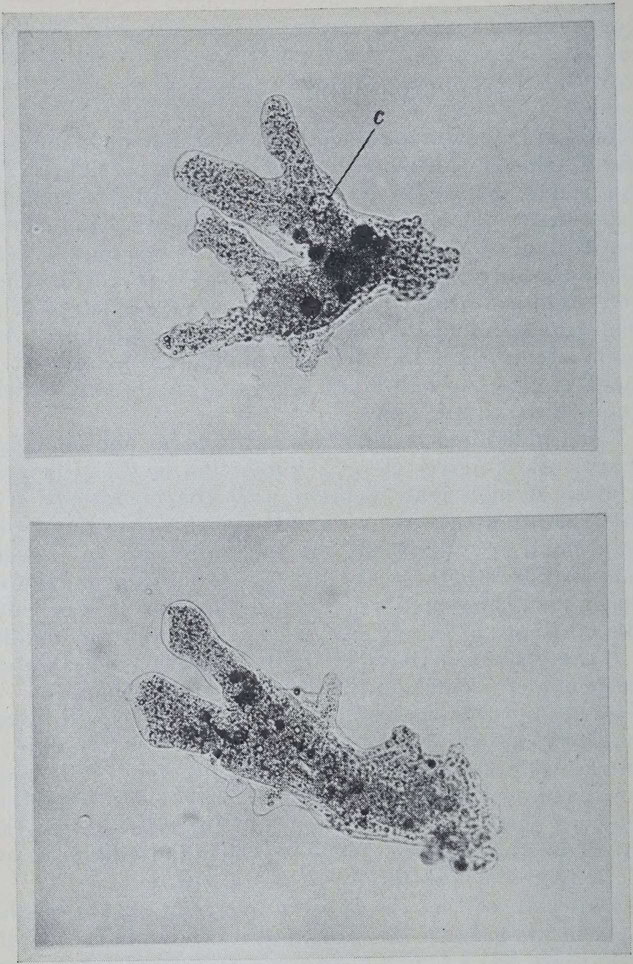

Fig. 16. *Amoeba*. These are two photographs taken through the microscope of living *Amoeba*. *c*. is the contractile vacuole. The round black balls are food vacuoles. The animals were moving towards the left by throwing out pseudopodia. (Karl Bělař.)

the *Amoeba.* Energy must be liberated from the digested food for movement and the other life processes. Just as in the case of other animals, oxygen is required for this purpose. The resulting carbon dioxide passes out again in solution into the surrounding water.

You will remember that our kidneys get rid of the nitrogen-containing wastes from the wear and tear of the living substance, and that also they excrete water. The *Amoeba,* too, has something that acts as a kidney. If you look closely at it, you will see a round bubble of liquid inside it which slowly grows and collapses, grows and collapses again, and so on at regular intervals. This is called the *contractile vacuole.* Each time it vanishes, the liquid inside has been squirted out of the *Amoeba.* In this way the animal excretes its waste matter. But there is another reason why it has all the time to be pumping water out of itself.

OSMOSIS. If you put a wrinkled grape into water it slowly swells up (Exp. 2). Water is sucked into it until no more can get in because of the skin of the grape. This intake of water is called osmosis. The reason for it is that dissolved substances inside attract water inwards through the skin. In the grape it is sugar that pulls in the water. The result is a pressure inside, called *osmotic pressure,* which swells out the grape.

You can make an experiment to show osmotic pressure (Exp. 3). Tie wet parchment paper over a glass thistle funnel. Put sugar solution into the funnel through the stem. Fix the funnel in a bowl of water with the parchment downwards, so that the level of water in the bowl is the same as the level of sugar solution in the stem of the funnel. The sugar will cause osmosis, attracting water in through the parchment. The osmotic pressure that results will force the sugar solution up the stem. The level will rise in the stem until the force of gravity, which is pulling the liquid downwards, stops the rise.

The outer surface of *Amoeba* is a skin or membrane like the skin of the grape or the parchment. Inside the *Amoeba* are sugar and other substances dissolved in water. As a result water is for ever passing inwards. But the membrane surrounding *Amoeba* is not tough like the skin round the grape. Consequently, unless something were done about it, the animal would soon burst owing to the osmotic pressure. This is the reason for the never-ceasing pumping out of water by the *contractile vacuole*.

RESPONSES. *Amoeba* moves, feeds, digests, respires and excretes. In addition it shows two other characteristics of all living organisms. It responds to changes in its surroundings, and it produces fresh generations of *Amoeba*.

If an *Amoeba* is touched with a needle, it quickly rounds itself up into a ball. The same thing happens if in the course of its wanderings it comes upon water with an unusual chemical in solution, or again if the microscope is shaken. *Amoeba* responds to changes in the world around it. Yet it has no nerves.

Any change in the outside world which causes a change in an animal or plant is called a *stimulus*. The needle, the chemical in solution, shaking the microscope, the small plant which it eats, are all stimuli to *Amoeba*. Light is a stimulus which causes flowers that have been closed at night to open in the morning. Stimuli act not only on the outside surface of the body but inside as well. Food arriving from the stomach into the intestine in ourselves is a stimulus causing a hormone to be liberated into the blood, and this hormone in turn is a stimulus for the pancreas to pour out its digestive enzyme (p. 23).

NUCLEUS. By looking carefully you can see that inside the *Amoeba* there is a round globule of clearer jelly. This is called the nucleus. It is not very easy to see, but can be made quite clear by killing the animal in a special way and staining it with a dye (Exp. 4).

The nucleus is a very important part of the *Amoeba* and controls all its activities. For instance, biologists have invented a very delicate apparatus by which even so small an organism as an *Amoeba* can be cut into two with very fine glass needles. When this is done the half containing the nucleus grows again and lives, while the other half always dies.

REPRODUCTION. How does the *Amoeba* reproduce its kind? It does so from time to time by dividing into two equal-sized individuals. Every few hours an *Amoeba* divides itself into two (Fig. 17). First the nucleus divides, then the rest of the animal divides into two equal parts with a half nucleus in the middle of each. The two halves then move away in different directions and each grows to a full-sized *Amoeba*. In this way a new generation is produced. But notice that there is no parent left to die of old age. Each family of *Amoeba* goes on indefinitely without dying, unless it meets with an accident.

*PARAMECIUM.* In the same sort of dirty water from a stagnant pond in which *Amoeba* lives, or in a flower vase that has been left too long, there are numerous other very small animals which move about much more quickly than *Amoeba* does. Instead of crawling on the bottom, they swim rapidly through the water. One of the commonest is called *Paramecium* (Fig. 18).

It is difficult to make *Paramecium* stop swimming, but this can be done by putting cotton-wool in the water between the cover-slip and microscope slide, or by a drop of gum at one side of the drop of water (Exp. 5). Then it is seen that the whole animal is covered with countless very small whips, which are lashing the water. They are called *cilia*. It is they that make the animal swim.

These cilia are not only found on microscopic animals. There are cilia in our own bodies, for example in the trachea (windpipe). Here they all beat upwards and make a current of sticky liquid (mucus) move on the walls of the trachea from the lungs towards the mouth. In this way specks of dust breathed into the lungs are got rid of. Cilia can be

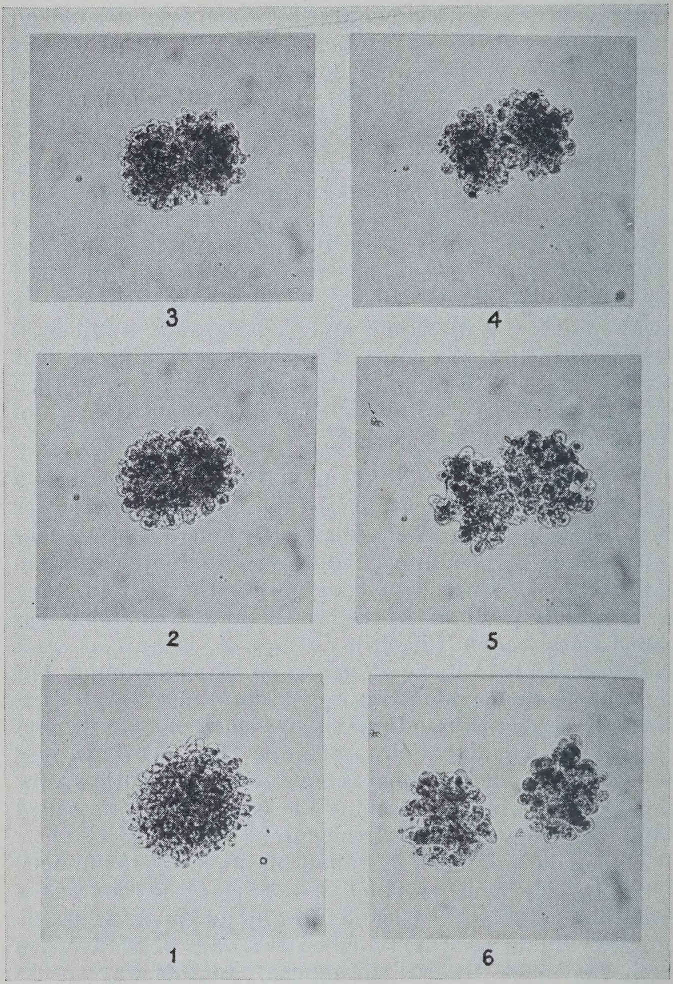

Fig. 17. Amoeba *reproducing*. 1–6 are six successive photographs of a living *Amoeba* dividing into two. Compare Fig. 134. (Karl Bělař.)

seen very beautifully in mussels (Fig. 19 and Exp. 6). These animals, by means of cilia, make currents in the water towards their mouth and so catch the microscopic animals and plants which are their food. Oysters do the same.

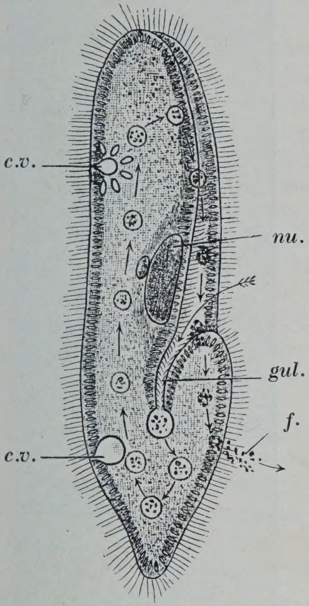

Fig. 18. *Paramecium.* Cilia are seen on the outside of the animal. Food enters the gullet (*gul.*). Food vacuoles are seen travelling round the body until finally faeces (*f.*) are thrown out. There are two contractile vacuoles (*c.v.*). *nu.* nucleus.

After the cilia, the first thing that you will notice about *Paramecium* is that it has a *definite shape*. It does not throw out pseudopodia like *Amoeba*. The animal is oval and flat. Indeed it used to be called the "slipper animalcule". Further, the body is slightly twisted, so that it swims turning over and over in a spiral course (Exp. 7). On one side is a groove. Special cilia cause water currents to flow into this groove, which is called the *gullet*. It is in this way that *Paramecium* takes in its food, which again consists of microscopic plants. When these are taken into the body of

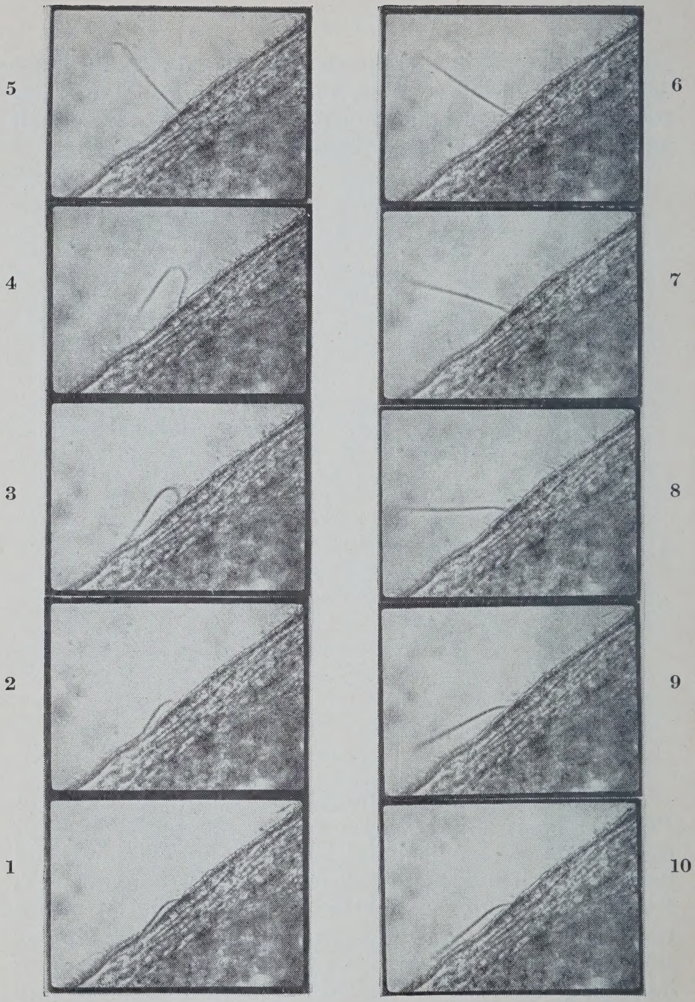

Fig. 19. *Action of a cilium.* Cinematograph film taken under the microscope of a single living cilium on the gill of a mussel. Successive stages in the beat of the cilium are shown by the numbers 1–10. The cilium comes up like a whip lash and moves back like a stiff rod. The interval between each photograph and the next is 1/20 second. The length of the cilium is 0·07 millimetre. (J. Gray.)

the animal they are, as in *Amoeba*, each enclosed in a *food vacuole* in which they are digested. These vacuoles slowly move around inside the body, following always the same path, and the undigested remains of the food leave the body always at the same place (Exp. 8).

It is clear, then, that the structure or anatomy of *Paramecium* is more definite than that of *Amoeba*. There is a gullet at the bottom of which the food enters the body as if by a mouth. It is true that there is no alimentary canal, but the food vacuoles follow a definite path. There is no visible *anus*, but the faeces leave the body always at the same spot. *Paramecium* has *contractile vacuoles* which in this case are two in number.

There are very many different kinds of animals similar to *Amoeba* and *Paramecium*. They are called *Protozoa*. Most of them live in dirty water, where they can get plenty of food, but some live inside the bodies of other animals for the same reason. They are present, for instance, in the intestine of the frog (Exp. 9).

PROTOPLASM. We have frequently spoken of "the living substance". Biologists call it protoplasm. The bodies of all animals and plants are made up of this stuff. They are made of living protoplasm plus the dead products of protoplasm. Examples of these non-living products are wood, bones, hair, and the outside layer of your skin. You saw protoplasm itself when you looked at *Amoeba* under the microscope. It was a semi-liquid greyish substance. And you know its chemical composition. It is made up of water with a number of substances dissolved in it, of which the most abundant are proteins. In addition to proteins, protoplasm contains carbohydrates, fats and salts.

The living substance protoplasm, then, is not one single chemical compound. It is what the chemists call a mixture —it is composed of numerous chemical compounds dissolved in water. But again, protoplasm is not just such a mixture as you might make by dissolving proteins and sugars and salts in water in a test-tube. It is much more complicated than such a mixture. For, as you know, chemical changes are going on in protoplasm all the time. Proteins are unceasingly being broken down to urea and being built up again from amino-acids. This we compared to the wear and repair of a machine. And carbohydrates and other compounds are all the time being broken down for freeing energy. This involves oxygen intake and carbon dioxide output (respiration). These processes go on regularly and unceasingly during life. If we can compare protoplasm to anything else, it is not to a mixed solution in a test-tube, but to a very complicated chemical laboratory. Death occurs when in some way or other the laboratory gets disorganized.

CELLS. When the living substance of a plant or a frog is looked at under the microscope, the protoplasm is seen. But this protoplasm is not just a single continuous mass. It is seen to be divided into innumerable little compartments. These are called cells. To see plant cells, skin off the outside layer of a leaf, and look at it through the microscope (Fig. 20 and Exp. 10). The easiest way to see animal cells is to scrape the inside of your cheek with your finger nail and then to put what you have removed in a drop of water on a microscope slide, covering it with a cover-slip (Exp. 11). These cells look like polygons fitted together.

The outlines of plant cells are plainer than those of animal cells. This is because each plant cell is surrounded by a layer of a dead product, the *cell wall*. The cell wall is made of a carbohydrate called *cellulose* (p. 4).

The word *cell* may seem to you unsuitable for something that is not an empty cell at all but a little mass of protoplasm. It is unsuitable, but its origin is this. In the seventeenth century Robert Hooke first cut thin pieces of cork with a razor and looked at them through the newly invented microscope. He saw numerous little empty compartments, which he aptly called cells. Cork, of course, is dead, and it was only found out later on that the empty cork cells had originally been filled with living protoplasm. Hooke was looking at the cell walls. But the word "cell" has been kept for the living protoplasmic divisions.

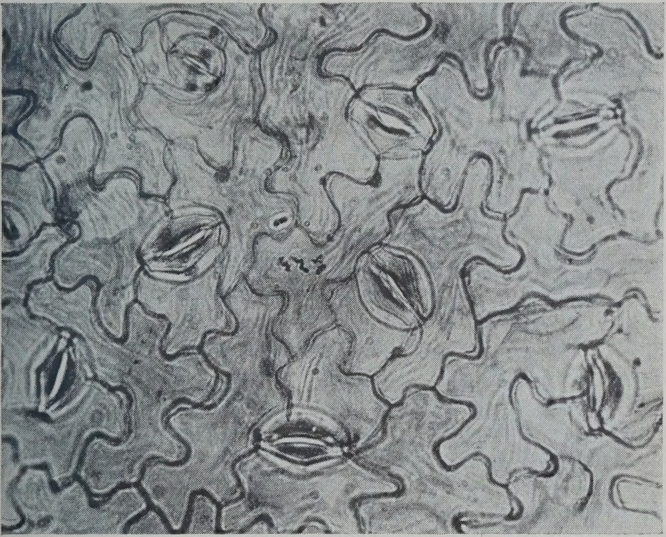

Fig. 20. *Surface of leaf*. This photograph taken under the microscope, shows the wavy cell walls of the cells at the surface of the leaf. Every here and there are stomata (p. 68).

Different kinds of cells. Protoplasm, as you know, is like a sort of liquefied jelly. The outside of the protoplasm of each cell is more solid. It is rather like the skin that forms on boiled milk. This skin or membrane is part of the living protoplasm. It prevents the liquid protoplasm of *Amoeba* from mixing with the water in which the animal moves. The cell wall around plant cells is distinct from the skin or membrane. The membrane is part of the protoplasm, while the cell wall outside it is a dead product of protoplasm. Inside the protoplasm of every cell is a *nucleus*, just as you saw in *Amoeba.*

The whole of the protoplasm in the body of an animal or a plant is divided up into cells.[1] The countless cells, however, which make up the body of an animal or a plant are not all of them alike. On the contrary, the cells of muscle, of the brain, of the stomach lining and so forth, are different from one another. But all muscle cells are similar, all nerve cells are similar, and so on.

BLOOD CORPUSCLES. Let us look at a few of these different kinds of cells more closely. You have already seen corpuscles floating in the frog's blood stream. These are cells. Looked at with a higher power of the microscope (Exp. 12) they are seen to be oval, with a nucleus in the centre of each. They are light yellow in colour. This colour is due to the *haemoglobin* they contain. It is only the countless corpuscles which are seen together in a drop of blood that make it look bright red.

Besides these *red corpuscles*, as they are called, blood contains *white corpuscles* floating in the plasma. They are less numerous, about one to every thousand red corpuscles. Nevertheless there are very many of them in the body. One cubic millimetre of the blood of a mouse, for example, contains over a million, and as there are about a thousand cubic millimetres of blood in the mouse's body, this small animal has a billion white corpuscles. These cells have an irregular shape, and a nucleus. Each looks something like an *Amoeba.* And, indeed, in more ways than one they resemble *Amoeba.* For they move about by throwing out pseudopodia, and they capture food in a similar way. Actually their food consists of any *bacteria* (microbes) which happen to invade the blood. The job of the white corpuscles is to eat bacteria and so defend the body.

COLOUR CELLS. When you looked through the microscope at the web of the frog's foot in order to see blood

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[1] This very important truth was first realized in 1838 by Schwann.

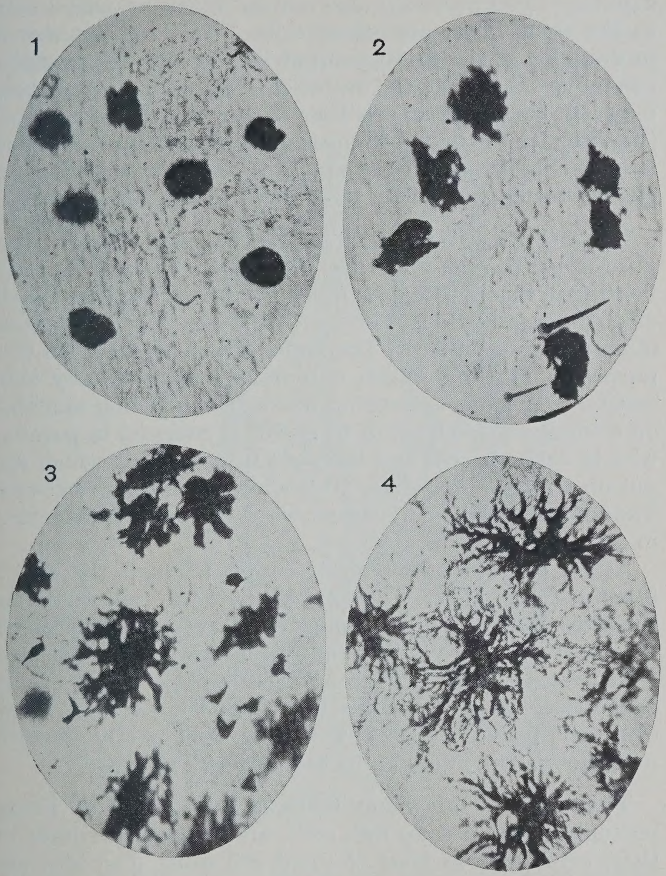

Fig. 21. *Colour cells in frog's skin.* These are photographs taken through the microscope showing successive stages in the spreading of black pigment into the branches of colour cells. As the black spreads into the cell branches, the animal looks darker in colour. (L. T. Hogben.)

capillaries you probably also noticed black branched cells in the skin. These are colour cells. The black pigment is in granules in the protoplasm of these cells. The granules can move out into all the branches of the cell. Or the black may all be collected together in the middle of the cell (Fig. 21). In the first case the frog looks dark, in the second case it is light coloured (Exp. 13). This is how the colour change occurs which you read about in the last chapter.

CELLS IN THE INTESTINE WALL. Blood corpuscles can be seen under the microscope because they are floating in blood. The cells lining the cheek can be scraped off to be examined. But how are we to study the numerous other cells in solid flesh? The biologist has invented for this purpose a machine which cuts dead flesh into very thin sections. It looks something like a bacon-slicing machine on a small scale. The stuff to be cut is enclosed in paraffin wax to make it stiff and then cut into sections which are put on a microscope slide, after which the wax is removed. The sections are dyed in various ways and made transparent in an oil.

As an example, look at a section through the frog's *intestine* (Exp. 14, cf. Fig. 22). You see the cells that line the intestine, each with its nucleus. You see parts of blood capillaries, their walls made of flattened cells. The digested food passes in solution through the lining cells into these capillaries. You see also muscles around the intestine. They cause the peristalsis (p. 7) that moves the partly digested food along. The muscle cells are long and narrow.

TISSUES. The whole body is thus made of living protoplasm divided up into cells, and of dead products of these cells, such as bone or plant cell walls. The cells are of various kinds, and the cells of each kind are massed together to form muscle, nerve, the inner lining of the intestine, and so on. In this way we get the different parts that make up the body. These are called tissues. There is *muscular* tissue, *nerve* tissue (nerves and brain), *skeletal* tissue (the cells that make bone and cartilage), *connective* tissue which holds the others together, *blood* tissue, *epithelium* (as the skin and the inner lining of the alimentary canal), and other kinds.

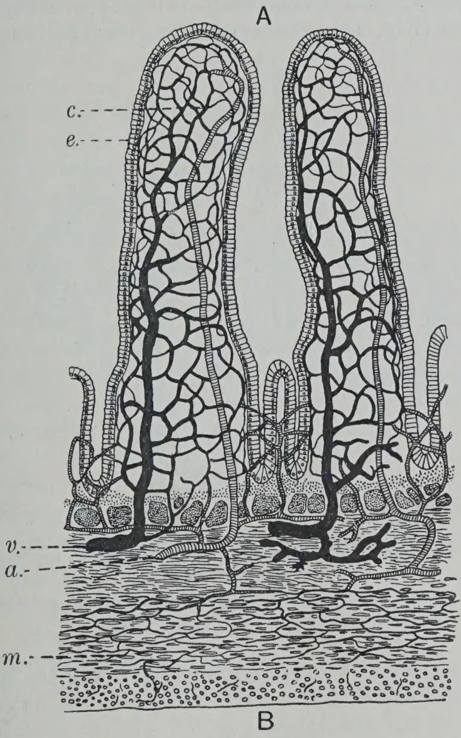

Fig. 22. *Part of a section through the wall of the human intestine.* A, cavity of intestine; B, body cavity. The finger-like processes project into the cavity of the intestine and increase its surface. *e.* epithelial cells through which digested food is absorbed into the capillaries, *c.* Blood flows from the artery, *a.*, through the capillaries into the vein, *v.* *m.* are the muscles which cause peristalsis.

ORGANS. What then are we to call the liver, the heart, the stomach, or the brain? These are organs. Each organ is made up of several different tissues. The *heart*, for example, is an organ made up largely of muscle tissue, held together by connective tissue. The *pancreas* is a type of organ known as a *gland* (Fig. 23). The cells of a gland produce (*secrete*) chemical substances (*secretions*) which leave the gland and are of use elsewhere in the body. The pancreas, as you know, secretes the enzyme trypsin which digests proteins in the intestine.

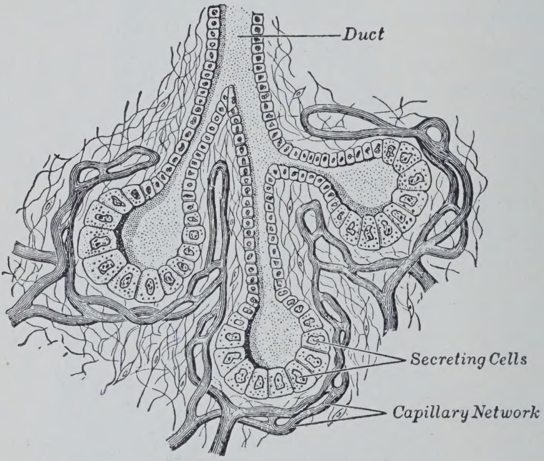

Fig. 23. *Gland.* The diagram shows the cells which secrete, the tube or duct by which the secretion leaves the gland, and the blood capillaries which bring to the gland the chemical substances from which it prepares the secretion.

VARIETIES OF PROTOPLASM. In this chapter you have learnt two of the most important general facts which are known about living organisms. The first of these is that all plants and animals are made of protoplasm. The second fact is that the protoplasm is always divided up into cells. Let us see what this really means.

It is truly very remarkable to find that the living substance of such different organisms as grass, man and *Amoeba* is so much alike. The protoplasm of each looks alike under the microscope. And chemically, too, these varieties of protoplasm are very much the same. The differences between them are only in the relative amounts of the various proteins and other chemical compounds which they contain. Yet the results of these small differences in the protoplasms are enormous. One variety of protoplasm produces a tree, another a dog.

CELL DIVISION. The protoplasm of all animals and plants is divided up into cells. The cells of a leaf and of our muscles may be very different in shape. So, too, the cells of our various tissues differ in appearance. Yet all cells are made on the same plan. Each has a nucleus, like *Amoeba*. And, more than this, just as one *Amoeba* divides into two, so also the cells of the body divide (Fig. 134). This is how *growth* takes place. As the animal or plant grows, the cells go on and on dividing, so forming fresh cells. Each of these grows to its full size and then divides into two again. Thus all cells in the body are the result of the division into two of previous cells. They never arise from something that is not a cell.

*AMOEBA* AND MAN. Finally, let us compare *Amoeba* with man. Each individual *Amoeba* is made of one cell. Man is made of an enormous number of cells. Yet you have seen that the single-celled *Amoeba* shows all the signs of life. It moves, digests, respires, reproduces, and so on. But it has no separate organs. All is done in one cell. In ourselves there are many different kinds of cell. They form the tissues, and each kind has its own special job, such as movement, digestion or support. The single cell of *Amoeba* is a man-of-all-work. But the human body is like a factory, with the different workers each having his own little task to do.

## PRACTICAL WORK

*Exp.* 1. Study living *Amoeba* under the microscope.[1] *Amoeba* can be cultured in water in which grains of corn are allowed to decay.

*Exp.* 2. Wrinkled grapes are immersed in water to show osmotic swelling.

*Exp.* 3. Osmotic pressure: explanation in text.

*Exp.* 4. Examine *Amoeba* stained to show the nucleus.

*Exp.* 5. Study living *Paramecium* under a cover-slip.

*Exp.* 6. Examine living cilia on a fragment of the gill of a mussel. The currents caused by the cilia can be seen better if starch grains stained with iodine are added to the water.

*Exp.* 7. Watch *Paramecium* swimming in a flat glass vessel under a low power of the microscope.

*Exp.* 8. Examine living *Paramecium* fed with Indian ink to show the food vacuoles.

*Exp.* 9. Examine ciliates from the frog's rectum swimming in 0·75 per cent. sodium chloride solution.

*Exp.* 10. Look through the microscope at plant cells in the skin of a leaf.

*Exp.* 11. Examine cells from the inside of your cheek.

*Exp.* 12. Examine a drop of frog's blood under the microscope.

*Exp.* 13. Examine under the microscope the web of the foot of (*a*) a frog made light coloured, and (*b*) a frog made dark by one of the methods of Chap. IV, Exp. 2.

*Exp.* 14. Look at a section through the frog's intestine.

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[1] It is very helpful to show this and other micro-organisms to the class with the help of a microprojector.

## *CHAPTER VI*

# HOW GREEN PLANTS FEED

YOU know what protoplasm is composed of. And you know that animals make protoplasm by feeding on plants or other animals, digesting the food, absorbing it into their blood, and then using what they have taken in. But how do plants feed?

Plants take substances out of the soil with their roots. This is known to everybody, since we manure the ground when plants have used up what is in it. But everybody does not know that plants also feed from the air. They use as food one of the gases present in the atmosphere. And they do this with the help of a green substance inside them. This is why most plants are green. Let us see first of all what it is that the plants take out of the air.

COMPOSITION OF PLANTS. The chemical compounds which make up protoplasm contain water, they contain carbon, and there are a number of other elements present. You can prove that there is water in plants by warming them and so driving off the water (Exp. 1). If you heat the plant still more it chars. The black charcoal is carbon (Exp. 2). The presence of nitrogen in the plant is proved by heating it with soda lime, when you get a smell of ammonia (Exp. 3). The charred plant contains also sulphur, phosphorus, potassium, calcium, magnesium, iron, and small amounts of other elements. Of these various elements it is carbon which the plant takes out of the air.

SOURCE OF CARBON. Air contains 0·03 per cent. of *carbon dioxide* gas, but this small amount is sufficient to supply green plants with all their carbon. The carbon dioxide goes into the *leaves*, and there it *combines with water*. The result is the formation of *glucose*. Glucose, as you know, is a sugar (one of the carbohydrates). It contains carbon, hydrogen and oxygen. These necessary elements are supplied by the carbon dioxide and the water. The equation is as follows:

$$\begin{array}{ccccccc} 6CO_2 & + & 6H_2O & = & C_6H_{12}O_6 & + & 6O_2 \\ \text{(carbon dioxide)} & & \text{(water)} & & \text{(glucose)} & & \text{(oxygen)} \end{array}$$

Once formed in the protoplasm of the leaves the glucose is quickly turned into another carbohydrate, *starch.* Starch is insoluble in water, so the turning of glucose into starch gets the carbohydrate out of solution, that is to say out of the way, as quickly as it is made. Room is thus left in the protoplasm for more glucose to be manufactured. Later on, when the carbohydrate is needed for various purposes, the starch turns into glucose again.

Light energy. Carbohydrates contain more potential chemical energy than water and carbon dioxide. So energy must be supplied to make the two latter unite and form glucose. In the laboratory we supply energy to make chemical combinations take place in the form of heat energy or of electricity. Light is another kind of energy which can cause chemical changes. This happens in photography. In the leaf it is light, the *light of the sun*, which supplies the energy to combine carbon dioxide with water.

Chlorophyll. But light cannot act directly on carbon dioxide and water. A solution of carbon dioxide in water in a test-tube will never turn into sugar, however strongly we light it up. In the leaf, however, there is a green substance which acts as intermediary. It is called *chlorophyll.* It is in the presence of this chlorophyll that sunlight causes the formation of glucose from water and carbon dioxide. The process is called *photosynthesis.*

Experiments. You can prove these facts quite easily yourself. If you expose lime water to the air, it slowly goes milky. This shows that *air contains carbon dioxide* (Exp. 4). Next, you can prove that *carbon dioxide* is *necessary for photosynthesis.* Take two young potted plants that have been kept in darkness for a couple of days. All the starch in their leaves will have been used up by then. Now put one of the plants into a closed glass jar in which you have placed a small beaker containing some caustic soda. This removes all carbon dioxide from the air. Put the second plant into a glass jar without any caustic soda. Then place both jars in sunlight for a few hours. You want now to see whether starch has been formed in the leaves of either of the plants. To find this out the chlorophyll must first be removed. Take a leaf from each plant, put it in boiling water for a minute and then into alcohol. The chlorophyll all dissolves out, leaving the leaf colourless. Next pour a solution of iodine on each leaf. With starch iodine gives a blue colour. The blue will appear only in the leaf that was able to get carbon dioxide (Exp. 5).

If the equation above is right, *oxygen* should be *produced* in photosynthesis. To prove this put a living green plant into one closed glass jar, and a dead plant, killed by placing it in boiling water for a moment, into a second jar. In each jar is a lighted candle. When the candles have used up all the oxygen they go out. After this has happened expose the jars to sunlight for a few hours. Then open the jars and put a lighted taper into each. It burns in the jar containing the living plant but not in the other, for the living plant has produced oxygen in the sunlight (Exp. 6).

Pond plants give off bubbles of oxygen in sunlight. The gas can be collected under the water and shown to be oxygen. At the same time you can see by means of an indicator dissolved in the water that carbon dioxide is used up, and so the water becomes less acid (Exp. 7).

LIGHT is really *necessary* for photosynthesis. If you take plants that have been some days in darkness the iodine test shows that their leaves contain no starch. The plants have used it up. But after the leaves have been put for some time in sunlight there is starch in them (Exp. 8).

Finally, it is easy to prove that *chlorophyll* is *necessary* for photosynthesis. There are some leaves which have green and yellow patches, for example certain kinds of laurel and privet. Put plants with such leaves in sunlight for some hours. Then make a drawing of the shape of the green patches. Next dissolve out the chlorophyll in alcohol, and test with iodine. The blue colour appears only where the chlorophyll had been (Exp. 9).

SOURCE OF NITROGEN AND OTHER ELEMENTS. It is clear now that carbon enters the plant from the air *via* the leaves. But the atmosphere contains 79 per cent. of nitrogen and it might be expected that this element too would be taken from the air. This is not so, however. The plant takes in all of its nitrogen in the form of *nitrates*[1] from the soil. And all the other necessary elements come in through the roots. The purpose of roots is partly to anchor the plant to the ground, partly to feed the plant.

You know what plant cells look like under the microscope (p. 51). Each is surrounded by a hard cell wall. It is obvious, therefore, that the cells of the root can only take into themselves substances which are in solution. Solids could not pass through the cell walls.

Actually the roots take in from the soil *solutions of simple salts*. The soil in which plants grow always has salts in it dissolved in water. The salts are chiefly *nitrates*, *sulphates*, and *phosphates* of *potassium*, *calcium* and *magnesium*. You can prove by experiment which particular salts are necessary to the plant (Exp. 10).

Some plants use more of one kind of salt, some more of another. For this reason the farmer grows first one crop, then another, on the same piece of land (*rotation of crops*).

You see now the great difference between the nutrition of green plants and of animals. Animals digest their food and then absorb the products into the body. But these products were quite complicated compounds, such as amino-acids and glucose. The plant, on the contrary, takes in carbon dioxide and simple salts.

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[1] Chiefly potassium nitrate, $KNO_3$.

ROOT HAIRS. If you grow cress seeds on wet blotting paper you will see that the young roots are covered by fine hairs. These root hairs are each of them a single long cell (Fig. 24). It is they which absorb the solutions from the soil.

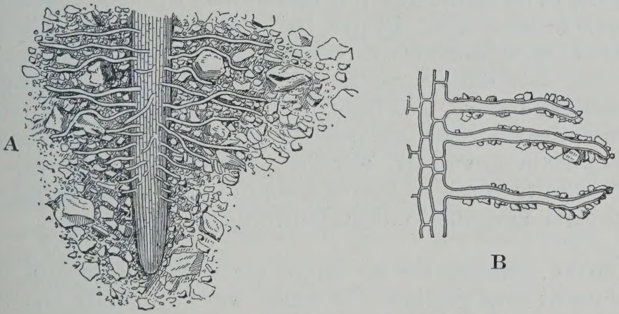

Fig. 24. *Root hairs.* A shows root hairs coming out from the tip of a root and penetrating the soil. B shows three root hairs more magnified. Each root hair is seen to be one cell. Soil particles are sticking to the root hairs.

It is easy to show that *root hairs absorb water*. If the cress seedlings are left in dry air, their root hairs shrivel up. Water evaporates out of them. But when the seedlings are put once more between wet blotting paper the root hairs swell out again by absorbing water (Exp. 11).

The *water* goes inwards into the root hairs owing to *osmosis* (p. 43). There is sugar inside the cells which attracts water inwards as it did into *Amoeba*. But in the plant cell there is no need of a contractile vacuole. The cell wall prevents the cell from bursting. Owing to osmosis the cell becomes swollen out with water just as a tyre is blown out with air and is prevented from bursting by its outer cover. The swollen plant cell is said to be *turgid*.

Water thus gets into the plant by osmosis. But the *salts* dissolved in the water which is in the soil *diffuse into the root hairs*. If you carefully put a drop of ink into a glass of water it gradually colours all the liquid. The molecules of ink slowly move, or diffuse, between all the molecules of water. The molecules of ink diffuse from places where they are numerous to places where they are few. The ink would diffuse in the same way if it had to pass through a piece of paper in the water. In just the same manner the salts in the soil water outside the root diffuse through the cell walls of the root hairs into the protoplasm inside. The salts *continue* to move, or diffuse, in this direction, because once inside the root they are quickly removed elsewhere, as we shall see in a moment. For this reason there is always less of the salts in the root hairs than in the soil, and therefore the salts continue to diffuse inwards.

SOIL. Before we go on to see what becomes of the solutions that get into the roots, we must study the soil quite shortly. Soil is composed of solid particles. They may be quite large, as in *sand*, or very small as in *clay*. Between the soil particles is air (Exp. 12). Around each particle is a *film of water* (Exp. 13), with salts dissolved in it. The salts form a very dilute solution. The water is held tight to the particles, just as water is sucked into blotting paper. The root hairs are so fine that they penetrate between the soil particles (Fig. 24) into these films of water, and so they can absorb the solution.

If it rains, water fills the *air spaces* between the soil particles. The rain water may then drain off, doing useful work by leaving behind it water films on the particles (Exp. 14). But if the water does not drain off, the soil becomes "waterlogged". This kills the roots, for there is no longer air between the particles and air is needed for the respiration of the roots.

But not only does rain water drain downwards through soil. If the soil is dry on top, water will creep up from below, just as it rises in blotting paper (Exp. 15). This helps to keep plants from drying up in dry weather.

Sandy soil dries quickly, but the fine particles of clay keep the water. The best soil for plants is *loam*, the particles being neither too coarse nor too fine. The upper layers of soil are darker in colour. They contain a brown material called *humus*, made by the breakdown of dead plants (Exp. 16). The chemical compounds in humus are too complicated to be absorbed by roots as food. But slowly they are broken down into simpler compounds by microbes (bacteria). Eventually they become the simple salts which plants take in. Humus not only supplies plant food but it also attracts water, so helping to keep water in the soil.

The *soil varies* in different parts of the country, and as a result of this the plants are different. Not only have the plants got different stems and leaves but their roots are suited to the soils. For example, when water is far below the surface the roots are long and deep (Exp. 17).

Soil is *dug* or *ploughed* in order to break it up. This allows roots to penetrate, it improves the drainage and it lets air in. We shall learn later on that earthworms do this work of breaking up the soil in uncultivated land.

FORMATION OF PROTEINS. The nitrates taken into the root from the soil are going to be used by the plant to build up proteins. *Proteins*, as you know, are compounds which form a very important part of living protoplasm. Since plants are always growing, more and more proteins are obviously required. Proteins contain the elements *carbon*, *hydrogen*, *oxygen* and *nitrogen*. For building up proteins, nitrogen is supplied by the *nitrates* from the soil. The other three elements come from *glucose*. Now, we saw that the glucose was manufactured in the leaves (where it was temporarily turned into starch for storage). It is in the leaves that the glucose and nitrates combine together. The result of the combination is *amino-acids*. You know already that these are the building stones out of which proteins are made in animals (p. 9). Once formed, these amino-acids are moved off in solution from the leaves all over the plant to be *combined together into proteins* wherever proteins are required for the production of fresh protoplasm.

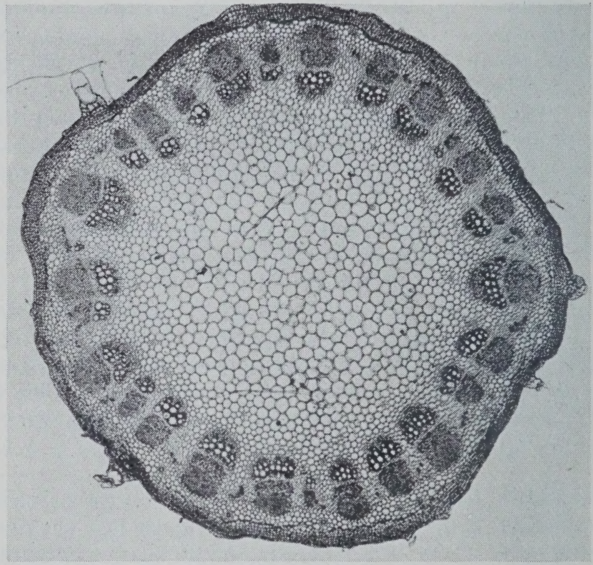

Fig. 25. *Vascular bundles.* Photograph taken through the microscope of a thin section cut with a razor through the stem of a sunflower. The cell walls of the cells in the stem, and the vascular bundles, are clearly seen.

VASCULAR BUNDLES. Since the combination of glucose and nitrates to form amino-acids takes place in the leaves, it follows that the *nitrates must move up the stem* from the root to the leaves. The nitrates and other salts absorbed from the soil into the roots pass up the stem in solution in water. There are *very small tubes* in the roots and stem along which the solution passes. These tubes are grouped together in bundles, called vascular bundles. By cutting a stem across, you can see them (Fig. 25 and Exp. 18). When they arrive at the leaves the vascular bundles divide up into many branches, called *veins.*

TRANSPIRATION. What is it that draws water with salts dissolved in it (the sap) up the vascular bundles? Leaves are all the time losing water into the air by *evaporation* (Exps. 19 and 20). The water lost is replaced by more water being drawn up the vascular bundles (Exps. 21 and 22). Evaporation of water from the leaves is called transpiration, and the current up from the roots which replaces the lost water is called the *transpiration current.* It carries the nitrates and other salts dissolved in the water.

It is very surprising what long distances water can be drawn upwards in vascular bundles by transpiration from leaves, when you think that there are giant trees in California over 250 feet high. You might have supposed that such long vertical columns of water would break. It is the cohesion, or sticking together of the water molecules, which enables these very long columns of water in the vascular bundles to hold together.

THE USES OF WATER IN THE PLANT. Transpiration moves the water with salts dissolved in it up the stem. It is this continual removal of salts away from the cells of the root that causes more salts to diffuse into the root hairs from the soil (p. 64). The *salts* are needed, as you know, for making new protoplasm. The *water* serves several purposes. First of all it is required to *dissolve the salts* and so move them up to the leaves. Secondly, water is the basis of all protoplasm, so the plant needs it for that reason. Thirdly, water is required to unite with carbon dioxide in *photosynthesis*, and so make glucose and starch. Fourthly, the evaporation of water *keeps the leaves cool* in the heat of the sun, just as you feel cool when wet after a bath. Fifthly, water swells out cells owing to osmosis. You saw that root hairs are *turgid*. All healthy plant cells are in this state.

The turgid state of the cells is one of the two ways in which plants keep stiff. When a cut plant *withers*, water is lost from the cells by evaporation, and, since the cells are no longer turgid, the plant becomes flabby. If you put the stem into water, more water is taken in by the transpiration current, and the cells absorb water again by osmosis, becoming turgid once more. The other means that plants have of keeping stiff is by a skeleton of *wood*. This is much more important than turgidity in large plants. Trees get all their support from wood.

THE STRUCTURE OF A LEAF. Let us see now just what the inside of the leaf is like, in which all these changes, photosynthesis, formation of amino-acids, and water loss, are taking place. If you strip off the outside layer of cells from a leaf and look at them under the microscope (Exp. 23) you will see that every here and there are pairs of cells unlike the others (Fig. 20). Between each pair is a hole leading into the inside of the leaf. The holes are called *stomata*. Through them carbon dioxide enters the leaf, and oxygen and water vapour leave the leaf.

Now look through the microscope at a thin *section* across a leaf (Exp. 24). The outer cells have cell walls which are thickest on the outside (Fig. 26). This thickening is the *cuticle*. Here and there you see a *stoma* cut across. On the upper side of the leaf, beneath the outermost cells, are long cells packed close together. Most of the chlorophyll is in these long upper cells, and in this way it best gets sunlight for photosynthesis. The chlorophyll is not evenly spread in the protoplasm, but is in small round bodies called *chloroplasts*. The cells in the lower part of the leaf form a sort of sponge with *air spaces* between them. Through these air passages the carbon dioxide gets in from the stomata to the cells with chloroplasts, and the oxygen (a by-product of photosynthesis) and water vapour (transpiration) get out to the stomata. In the section you will also see *veins*, or vascular bundles, cut across.

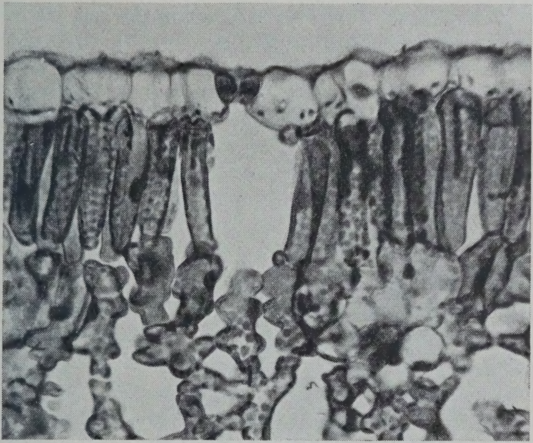

Fig. 26. *Section of part of a leaf.* This photograph taken through the microscope shows the cells composing a leaf. The uppermost cells have cuticle on the outside. The numerous small round bodies in the other cells are chloroplasts. A stoma is seen in the middle of the upper surface, leading into a large air space. There are air spaces between the lower cells.

WATER ECONOMY. Plants have to be very careful not to lose too much water in transpiration. This is the reason for cuticle, stomata and air spaces. You will remember the reason why our skin has a dead layer on the outside, and our lungs are enclosed inside the body (p. 26). For the same reason the leaf has *internal air spaces*, where evaporation is small, and a *cuticle* on the outside through which very little water can pass. And more than this, when the air is very dry, and therefore evaporation is great, the *stomata* close for the time being.

When the temperature of the soil is low, roots can absorb less water. So in winter there is a danger that more water would be lost by the leaves than could be replaced. Plants get over this difficulty in various ways. Most trees *shed all their leaves*. Then transpiration ceases. Others, the *evergreens*, like the holly and pine, have leaves with very thick cuticles. Still others, the *annuals*, such as the groundsel and the pea, die down altogether in winter, surviving through the cold season as seeds.

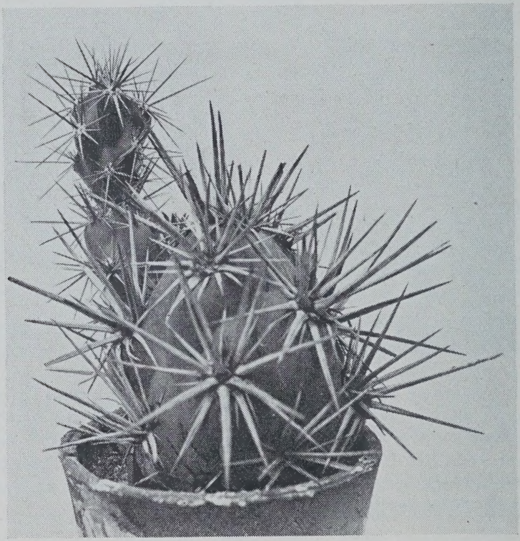

Fig. 27. *Young prickly pear cactus.*

We have seen that different soils account largely for different kinds of vegetation. But the amount of water in the atmosphere is another very important reason. A *desert flora* is very different from the flora of a rainy country. For the plants in a dry land have to do everything to economize water. Many of them, such as cactus plants (Fig. 27), are *fleshy*. They keep stores of water, absorbed on the rare occasions when they can get it.

ENERGY SOURCE. You know now how plants feed, and how they build up proteins to make new protoplasm. They manufacture carbohydrates (glucose and starch) by photosynthesis in the leaves. Nitrates from the roots come up through tubes in the vascular bundles to unite with the glucose and form amino-acids. These amino-acids are then moved away from the leaves, through other tubes in the vascular bundles, to all parts of the plant, where fresh proteins are to be made for new protoplasm.

But for most life processes *energy* is required. It is needed for growth, and for the movements of petals or leaves. It is needed to maintain the complicated chemical laboratory with which we compared protoplasm (p. 50) in working order. What is the source of this energy? Animals take potential energy into their bodies bound up in the carbohydrates, etc., of their food. Plants do not do this. Energy enters them in the form of light, and it is stored in potential form in the carbohydrates (glucose and starch) which they manufacture. Carbohydrates, then, contain energy both for animals and for plants. But while animals get their carbohydrates ready-made in their food, *plants put the energy from sunlight into carbohydrates for themselves.*

In animals energy is *liberated* from carbohydrate molecules which come from the food. In muscle, for example, carbohydrate is broken down to lactic acid, and the energy thus freed is used to build up a phosphorus compound, which, in turn, supplies energy for contraction (p. 11). But in plants the carbohydrate is not taken in as food. Glucose is first formed by photosynthesis in the leaves. Some of it is then broken down again on the spot as energy is required, oxygen being used up in the process. And some of the glucose is moved away *via* the vascular bundles to all the other parts of the plant to be used there to liberate energy.

But, just as in animals (p. 8), the carbohydrate has one of two fates. Part of it is used in this way to supply energy and part of it is required as one of the building materials for fresh protoplasm.

RESPIRATION AND PHOTOSYNTHESIS. In plants, for energy to be liberated from carbohydrate (glucose), oxygen is used up. The final breakdown products are carbon dioxide and water:

$$C_6H_{12}O_6 \text{ (glucose)} + 6O_2 \text{ becomes } 6CO_2 + 6H_2O.$$

This is *respiration* (cf. p. 12). Oxygen is taken into the plant for respiration and carbon dioxide is given out (Exp. 25).

But you will notice that this is exactly the opposite of what happens in photosynthesis. For in photosynthesis carbon dioxide goes into the leaves and oxygen comes out. In other words, the glucose is broken down in respiration just as it was built up in photosynthesis. *What happens, then, in green leaves?* Do carbon dioxide and oxygen go in or come out?

The answer is this: in darkness respiration alone occurs. Oxygen goes into the leaves and carbon dioxide comes out, *via* the stomata. But in sunlight, although the same amount of respiration goes on as in darkness, photosynthesis is much more active than respiration. So now carbon dioxide goes in and oxygen makes its exit.

ANIMALS DEPEND ON PLANTS. Animals require proteins, fats and carbohydrates in their food. They cannot live without eating foods containing these compounds. But the only place in the world where these substances exist is in the bodies of other animals or of plants. Green plants, on the other hand, require only water, salts and carbon dioxide. It is clear, then, that all animal life on the earth must depend on plant life. Without green plants animals would get no food. It is true, of course, that carnivorous animals eat other animals, but these must get their food from plants. Animal life, in the end, exists thanks to chlorophyll and sunlight.

## APPENDIX

# UNUSUAL WAYS OF PLANT NUTRITION

THE SUNDEW. There are just a few plants which feed on animals. One of them is the sundew which grows in boggy places. The leaves have hairs on them with sticky tips. When a small fly touches these it is held fast. Other hairs slowly bend over the insect and pour out digestive

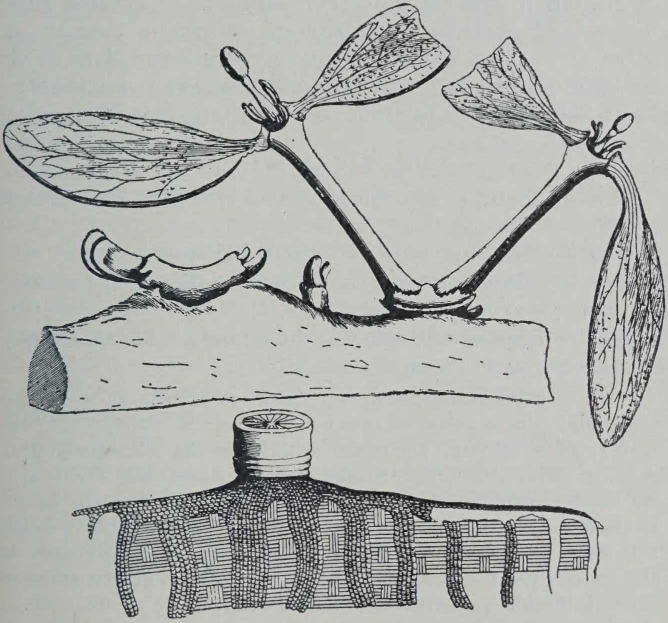

Fig. 28. *Mistletoe*, drawn by Malpighi[1] in 1679. Above: two young and one older mistletoe plants growing on a branch of a tree. Below: roots of the mistletoe penetrating into the tree's tissues.

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[1] Pronounced in Italian "Mal-pee-gee", with the accent on the middle syllable and the "g" hard.

enzymes on to it. The leaf then absorbs the digested tissues of the animal. The sundew is green: it carries on photosynthesis of carbohydrates. But it gets its nitrogen compounds from animals, not from the soil: it is *carnivorous*.

THE MISTLETOE. This is a plant which has chlorophyll, but it gets its water and salts out of another plant instead of from the soil. It is found growing on the oak and other trees (Fig. 28). The roots penetrate the stem of the oak and absorb the solutions out of its vascular bundles. Since the mistletoe lives on another living plant it is called a *parasite*.

## PRACTICAL WORK

*Exp.* 1. Warm pieces of a plant in a test-tube: they give off water.

*Exp.* 2. Heat a piece of plant until it chars.

*Exp.* 3. Heat crushed peas with soda lime in a test-tube. Ammonia is given off.

*Exp.* 4. Expose lime water to the air until it becomes milky.

*Exps.* 5 and 6. Explanation in text.

*Exp.* 7. Fill a beaker with tap water containing brom-thymol blue, and put a piece of pond weed such as *Elodea* into the water. Blow through the water until its colour becomes yellow. Arrange an inverted filter funnel over the plant with the stem of the funnel projecting into an inverted test-tube full of the water. Expose the beaker to sunlight. Bubbles of gas will collect in the test-tube. The gas can be shown to ignite a glowing splinter. At the same time the colour of the indicator changes to green as carbon dioxide is abstracted from the water.

*Exps.* 8 and 9. Explanation in text.

*Exp.* 10. Grow bean or pea seedlings until the roots are a few inches long. Prepare four quart jars with flat corks and label them *a*, *b*, *c* and *d*. Fix each seedling into a cork having a hole in the middle of it and a slit from the hole to the edge. Make another hole in each cork for a stick to tie the plant to. Put the solutions given below into the jars. Keep plant and cork quite dry. Darken the roots by brown paper round each jar. Add distilled water periodically to make up for evaporation.

Prepare the following solutions. Dissolve in 1 litre of distilled water: (*a*) 1 gram calcium nitrate, 0·25 gram each of magnesium sulphate and potassium acid phosphate, 0·1 gram potassium chloride, and add 2 drops of iron chloride; (*b*) the same with calcium sulphate in place of calcium nitrate; (*c*) as (*a*) but sodium chloride in place of potassium chloride, and sodium phosphate instead of potassium phosphate. Put these solutions into jars *a*, *b* and *c* respectively, and put distilled water into jar *d*, filling each jar three-quarters full of liquid.

Watch and measure the growth of the seedlings in each jar.

*Exp.* 11. Grow cress seedlings between two layers of wet blotting paper. Examine the root hairs with a lens. Expose the plants to dry air; the root hairs collapse. They swell out again in damp air under wet blotting paper.

*Exp.* 12. Plunge a flower pot full of soil under water: bubbles rise to the surface. This is air from between the soil particles.

*Exp.* 13. Weigh some fresh soil. Dry it in an oven for a couple of hours. Re-weigh it. It loses water.

*Exp.* 14. Put a perforated tin disc in a funnel. Place some dried soil in the funnel. Pour a measured volume of water on the soil. If you measure the water that runs through, it will have less than the original volume.

*Exp.* 15. Tie muslin on one end of a lamp chimney. Fill it with dried and powdered soil. Stand the muslin-covered bottom in water. Sow cress seeds on the top. Water will rise and allow the seeds to sprout.

*Exp.* 16. Mix some soil with water so as to make a paste. Put this in a bottle, fill with water and shake it up thoroughly. Leave the bottle for some time. Sand grains go to the bottom, smaller clay particles settle above this, and at the top is the black humus.

*Exp.* 17. Examine the roots of plants which grow in various different soils.

*Exp.* 18. Cut across the stem of a wallflower or other plant with a sharp knife and look at the vascular bundles with a lens.

*Exp.* 19. An inverted glass bottle with a wide mouth is placed over a young growing plant. A cork is bored to fit the stem, cut in two so that it can be placed round the stem, and then fitted into the mouth of the bottle. Water drops appear on the inside of the bottle.

*Exp.* 20. Take a plant growing in a pot and cover the soil with an india-rubber sheet to prevent evaporation. When the pot is put on the scale of a balance, the loss of water from the leaves can be measured.

*Exp.* 21. Cut the end of a grass or narcissus leaf under red ink, and watch the ink rise in the vascular bundles.

*Exp.* 22. The transpiration current can be demonstrated and its rate measured under different circumstances as follows. Make three holes in a cork bung fitting into a wide-mouthed bottle. Into one hole place the cut stem of the branch of a shrub. It must fit exactly into the hole. Into the second hole fit a glass funnel with a stopcock. Make a right-angled bend at one end of a piece of thermometer tubing about a yard long. Fit the bent end into the third hole in the bung so that the long limb of the tube is horizontal. Pour water through the funnel until the bottle is completely full and the water flows to the open end of the thermometer tube. Close the stopcock. Transpiration will cause the water to move inwards along the thermometer tube. The rate of movement can be measured. The plant can be placed in sunlight and in the shade, it can be covered with a bell jar and be exposed to a draught, to show the varying rates of transpiration.

*Exp.* 23. Strip the outer layer off a leaf of narcissus or bean, mount it in water and examine it under the microscope.

*Exp.* 24. Examine a section across a leaf under the microscope.

*Exp.* 25. Put onions sliced in two, or sprouting beans, into a closed jar. Keep the jar in a warm place for a day. Pour the carbon dioxide gas formed into a jar of lime water and shake.

## *CHAPTER VII*

# COLOURLESS PLANTS

### I. YEAST

All plants are not green. Some of them have no chlorophyll. The mushroom, for instance, has none. Such *colourless plants* are not able to manufacture their own carbohydrates. They cannot manage photosynthesis. Like animals, they have to get their sugars ready made. As to the source of their nitrogen, different colourless plants take in this element in the form of various quite different compounds.

One of these colourless plants is *yeast*. It is put to two uses by man, for brewing and for making bread. Just as *Amoeba* is an animal which is a single cell, so yeast is a *one-celled plant*. It lives in water that has the necessary food in solution in it. Looked at under the microscope, yeast cells have an oval shape (Fig. 29 and Exp. 1). Some of the cells have bumps on their sides. These cells are multiplying. A yeast cell reproduces by this very simple means of growing out a new cell, or *bud*, on its side. Later on the new cell comes free. Sometimes a bud, before it has come off, forms another bud on itself. In this way whole chains of yeast cells may be formed. In a proper food solution, yeast reproduces at an enormous rate, so that a very short time after a few cells have been put into the liquid, it is swarming with their descendants.

Fermentation. A food solution suitable for yeast to grow in must contain sugar, in addition to other chemical compounds. The plant takes in glucose. Like other plants, it uses part of the sugar to combine with nitrogen compounds and so build up proteins, and part of it for energy liberation. But the latter is peculiar. For yeast can do without oxygen. This is called *fermentation*. Instead of glucose being broken down and finally oxidized to carbon dioxide and water for the freeing of energy as in the respiration of other plants and animals, glucose can be turned by yeast into *carbon dioxide* and *alcohol* without any oxygen being taken up (Exp. 2). The equation is as follows:

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} = \underset{\text{(alcohol)}}{2C_2H_6O} + \underset{\text{(carbon dioxide)}}{2CO_2}$$

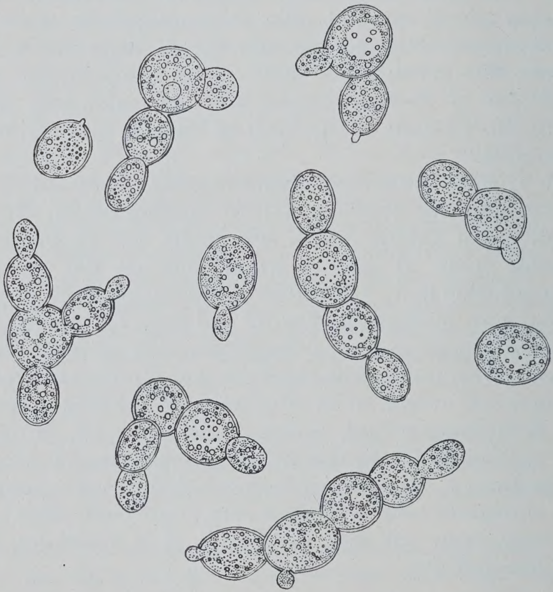

Fig. 29. *Yeast cells* under the microscope. Successive stages of budding are seen, leading to the formation of chains of cells.

The yeast can free energy in this way for its life processes. But it gets much less energy by fermentation than if the glucose molecules were completely broken down and finally oxidized to carbon dioxide and water as in respiration (pp. 12 and 72). You can easily understand this when you think that one of the products, namely alcohol, still contains a lot of energy. You could get this energy out of alcohol by burning (oxidizing) it. In consequence of this, to obtain a certain definite quantity of energy twelve times more sugar must be fermented by yeast than if the sugar had been completely broken down in respiration. For this reason a relatively small amount of yeast uses up large quantities of sugar and produces correspondingly large amounts of alcohol.

BEER AND WINE. This power of yeast to turn a large quantity of sugar into alcohol is made use of in brewing beer and making wine.

In making *beer*, barley grains are first wetted, so that they sprout. When the grains sprout, the starch in them turns into sugar (p. 187). It is this sugar that is going to be fermented later on by the yeast. The sprouting grains are next heated to kill them. The product is called *malt*. Then malt is put into hot water to dissolve out the sugar. The resulting liquid is *wort*. This is boiled with *hops*, which give a special taste. Finally *yeast* is added to the cooled liquid and the yeast slowly makes alcohol from the sugar. Thus the liquid turns into beer.

For *wine*, the sugary liquid to be fermented is made by pressing ripe grapes. No yeast has to be added, for it is always present on the outside of the grape skins. The different kinds of wine depend on the kind of grape used and on the soil and climate in which it has grown. For sparkling wines, the last stages of fermentation go on in the bottles so that the carbon dioxide is retained, getting up a considerable pressure.

Yeast is used by bakers to leaven the *bread*. Carbon dioxide gas from the fermentation makes holes in the dough and so the bread is light.

## II. BACTERIA

BACTERIA, or microbes as they are popularly called, are made up of one cell only, like yeast. But bacteria are smaller than yeast. A bacterium is almost the smallest living thing.[1] Some bacteria are not more than $\frac{1}{1000}$ millimetre long. Yet bacteria are of quite extraordinary im-

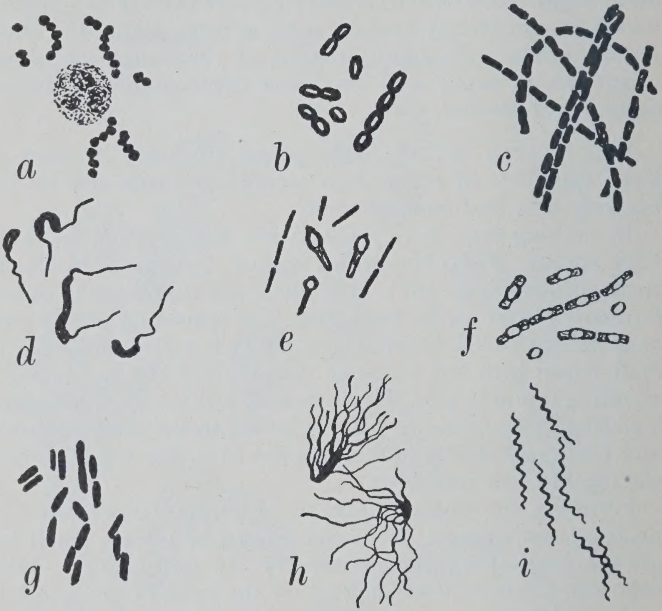

Fig. 30. *Bacteria.* Various different kinds are shown. Some are chains, because when the cells divide the new cells do not at once move apart. *d* and *h* have cilia by which they move. Spores are forming in *e* and *f*.

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[1] A *virus* is smaller still. Some viruses are parasites in the human body causing certain diseases, for example measles and small-pox.

portance in nature, just as green plants are immensely important.

Green plants build up protoplasm from the simplest chemical compounds. Bacteria break down the substance of dead animals and plants, finally turning it again into those simple compounds which are the food of green plants. Without bacteria the earth would be littered with dead plants and corpses. Bacteria, too, as you will see, change the nitrogen of the air, which is useless to green plants, into nitrates in the soil which crops can use. Thus they are of great importance in agriculture. Bacteria are also of direct importance to man in another way. For some of them cause deadly diseases. And, like yeast, other bacteria produce useful fermentations, such as in the ripening of cheese, the production of vinegar, and the curing of tobacco.

Bacteria are of various different *shapes*. Fig. 30 shows a number of them (Exp. 3). They live in water which contains substances in solution serving as their food.

REPRODUCTION. Bacteria reproduce by the cell *dividing into two cells*, each of which then grows to the full size. This reproduction and growth is extraordinarily rapid. A bacterium may divide into two every twenty minutes. If it only does this once every hour, over a million individuals will arise from a single bacterium in a day.

SPORES AND DISTRIBUTION. A thick wall is often formed within the cell of a bacterium. The protoplasm surrounded by this thick cell wall is called a spore. The spores are extremely hardy. They are not killed by *drying* like the ordinary form of the bacteria, and they survive being *heated* to higher temperatures than these can stand.

Spores are blown about in the *wind*, and this is the way that many bacteria are spread from place to place. Those kinds of bacteria which do not form spores are spread about in very small drops of water attached to dust particles in the air.

PUTREFACTION. The food of different kinds of bacteria is very different. Many live on *proteins, cellulose* and other substances that make up animals and plants. When the animals or plants die, bacteria, arriving with the wind, use their bodies as food. The bacteria use some of the chemical substances in dead animals and plants *to build up their own protoplasm.* They use much of these substances *to get energy.* Sometimes oxygen is required (*respiration*), sometimes no oxygen is needed (*fermentation*). The result is the breakdown of dead bodies. This is called decomposition or putrefaction. Many of the compounds that result are evil-smelling gases. When the work of bacteria on a dead animal or plant is finished, and various gases have gone off into the air, among the substances remaining there are *compounds of nitrogen.* Other bacteria then turn these compounds into *nitrates.*

CIRCULATION OF NITROGEN. You see then that not only do bacteria clear corpses out of the way so that there is room on the earth for more animals and plants, but they also make proteins into simpler nitrogen compounds, which can become the food of green plants. The proteins of dead bodies are useless to green plants as food. But bacteria turn them into nitrates, which you know to be the nitrogen source for green plants, to be built up again into proteins in the plants. In this way there is a never-ending circulation of nitrogen through green plants, bacteria, and green plants again. Or it is through green plants, animals which eat them, bacteria, and then green plants.

NITROGEN FIXATION. In putrefaction some nitrogen goes off into the air as gas. But you know that this is useless to green plants. How is it then that the nitrogen which plants can use is not always getting less and less? The reason is that there are certain bacteria which use nitrogen gas to build their protoplasm. They "fix" nitrogen. When they die their protoplasm decomposes in the usual way and the nitrogen again appears as nitrate. Many of these bacteria live in the soil, and some of them live inside the roots of plants of the pea and bean family (Exp. 4). The bacteria take in and use nitrogen out of the air which is between the particles of soil.

When crops, for example of corn, have used up most of the nitrates in the soil of a field, the farmer grows plants of the pea family, such as clover. Later on he ploughs their roots into the land. This enriches the land with nitrogen compounds because the bacteria in the roots of the clover have taken into themselves nitrogen from the atmosphere.

CIRCULATION OF CARBON. Carbon dioxide is taken from the air by green plants and built by photosynthesis into carbohydrates. It returns to the air when plants and animals respire. Carbon dioxide gas is also given off into the air in putrefaction. So there is not only a circulation of nitrogen but also of carbon (Exp. 5).

STERILIZATION. Bacteria, like all living things, are killed by *heat*. The spores can stand heating best, but all spores are killed at 120° C. when moist. When not in the state of spores, 50° C. is enough to kill most bacteria. When food is to be preserved in tins it is first cooked. The heat kills all bacteria which otherwise would have caused the food to putrefy. The tins are then sealed to prevent other bacteria from getting in. *Cold* does not kill bacteria, but it stops their activities and reproduction. Hence cold storage keeps meat from going bad, and larders should be kept cool.

Water can be freed from bacteria, or *sterilized*, by heating it or by passing it through a filter. This may be made of porcelain. In the water supply to towns the water is treated with chemicals which poison the bacteria, and it is filtered through beds of sand to trap them.

You could not tell by looking at a drop of drinking water under the microscope whether or not it had bacteria in it, for they are in any case too few and far apart to be seen. The way the water is tested is this. A drop of the water is put into a sterilized soup, or on to the surface of a sterilized jelly, containing food for the bacteria. If any are present in the drop they will soon multiply so much in the soup or on the jelly that they can be seen and studied under a microscope.

SPONTANEOUS GENERATION. It was believed once that frogs were formed from mud and worms from dead animals. Long after it had been proved that this was false, it was still thought that bacteria might be formed by putrefaction. This was difficult to disprove, because the spores blown by the wind are so small. But the great French biologist Pasteur settled the question seventy years ago. Soups, or other foods for bacteria, can be sterilized by heating, and then they will remain sterile for ever provided they are shut off from the air. This proves that bacteria arise only from other bacteria. All living cells arise from the division of other living cells.

When life first appeared on the earth, cells must have been formed out of something which was not living. But to-day there is no evidence that any cells, whether bacteria or others, can suddenly appear out of something that is not living.

DISEASE. Some bacteria live and feed, not on dead bodies, but on living animals. They are *parasitic*. We have met with one parasitic plant already, the mistletoe. This is an *external parasite*. It feeds from another plant, its *host*, but is on it, not inside it. The flea is an external parasite on its host, man. But some bacteria can live inside our bodies. They are *internal parasites*. It was again Pasteur who first showed that many diseases are due to such bacteria. This great discovery was the commencement of modern medicine.

Diseases are caused by certain chemical substances which are formed by the bacteria. These substances are the excretions or waste products of the bacteria living in our blood or tissues, and they upset the delicate and complicated chemistry of our bodies. The result is disease.

INFECTION. Such parasitic bacteria can get into the body in one of two ways. One way is through a wound. Dirt containing the bacteria may infect the wound. The other way is through the throat. Our mouths and throats contain many different kinds of bacteria. Some, if they got into the blood, would cause a disease. But in the ordinary course they cannot get in. Only when, from some reason or another, the chemical defences of the body are weakened by ill health do the bacteria make a breach and get in, and then the fat is in the fire.

A diseased person may have in him bacteria which are not present in our own mouth at all, or at any rate bacteria which are in a much more active and dangerous condition than those in our mouth. We can get infected either (1) by touching the diseased person, getting bacteria on to our fingers from his mouth or a wound, and then putting them into our own mouth. Or (2) he may infect us by coughing or sneezing and so filling the air with bacteria which we then breathe in.

ANTISEPTICS AND ASEPTIC SURGERY. Modern surgery is possible both owing to *anaesthetics*, like chloroform or ether which put the patient to sleep, and to *antiseptics*, such as carbolic acid and iodine. Antiseptics are placed on a wound or surgical cut to kill bacteria which would infect it from the air and cause blood poisoning. Lord Lister introduced antiseptics half a century ago. But surgical operations to-day are not only antiseptic, they are also *aseptic*. This means that the hands of the surgeon, his instruments, and the dressings, are all sterilized and so are free from any bacteria.

IMMUNITY. If a person recovers from a disease, the course of the disease is as follows. First the bacteria in the blood multiply enormously and the patient is ill. Then slowly the body manufactures chemical substances which harm the bacteria. These substances are called *antitoxins*. Either the antitoxins will kill the bacteria in the body or they make the bacteria tasty for the *white blood corpuscles* in the blood. You will remember that these are like *Amoeba* (p. 52). They eat and digest the bacteria. Then the corpuscles in turn die. When large numbers of dead corpuscles are together they form *pus*.

Now, everyone knows that when a person recovers from a disease, such as scarlet fever or measles, he cannot catch the illness again, at least for some time. He is said to be *immune*. This is because the body has made so much antitoxin that it prevents any of the particular kind of bacteria which cause that disease from living if they happen to get into the blood again.

But it is possible to make a person immune to a disease without his ever having it. There are several ways of doing this, according to the particular disease. For small-pox the method is *vaccination*. People are given a very mild attack of a disease of the calf which resembles small-pox. In reply the human body makes quantities of small-pox antitoxin. For typhoid, *inoculation* is practised. Dead typhoid bacteria are put into the body by means of a hypodermic syringe. The result is the production in the blood of the typhoid antitoxin.

## III. FUNGI

MOULDS which grow on food that is going bad are plants. They are colourless plants without chlorophyll, like yeasts and bacteria. They only grow in places where the air is damp. One of the commonest moulds is called *Mucor*. If you look at it with a lens (Exp. 6), you will see a lot of thin white threads which branch (Fig. 31). If the mould is growing on jam some of the threads are in the air, others are down inside the jam. The threads of *Mucor* are not divided into cells like other plants. Inside the cell wall the protoplasm with its numerous nuclei is not divided up by partitions.

FOOD. *Mucor* takes in its *carbon* in the form of sugar. It can take its *nitrogen* from various different nitrogen compounds. It can grow on such simple compounds as nitrates, but *Mucor* flourishes on much more complicated nitrogen food. It can live on dead plants or animals, where bacteria are breaking down the proteins. The mould takes in the still complicated nitrogen compounds that result from the first stages of putrefaction. Such plants which feed on the juices of *dead* plants or animals are called *saprophytes*. Parasites, you will remember, feed on the living bodies.

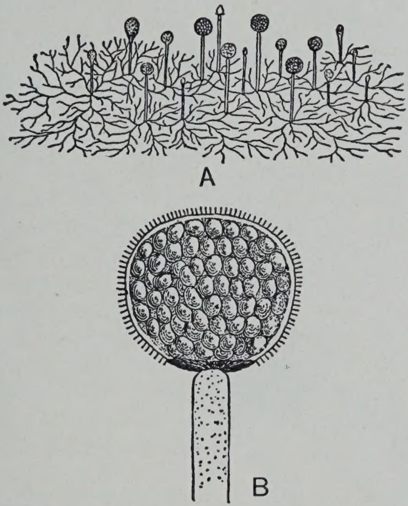

Fig. 31. *Mucor*. A shows the branching threads with sporangia at the tips of the upright branches. B is a sporangium more magnified. It is packed with spores.

*Mucor* requires *oxygen* for its respiration. The threads only penetrate into the top layers of jam, for there is not enough oxygen further down.

REPRODUCTION. *Mucor* reproduces in two ways. The commonest way is by the formation of *spores*. Branches of the threads grow straight upwards. On the top of each branch is a knob, called a *sporangium* (Fig. 31). Each sporangium with its stalk looks like a small pin. Inside the sporangia are numerous round spores. When the sporangium is ripe its wall bursts and the spores are shot out. They float about with dust in the air. Such spores are everywhere in the air, and so all food when damp goes

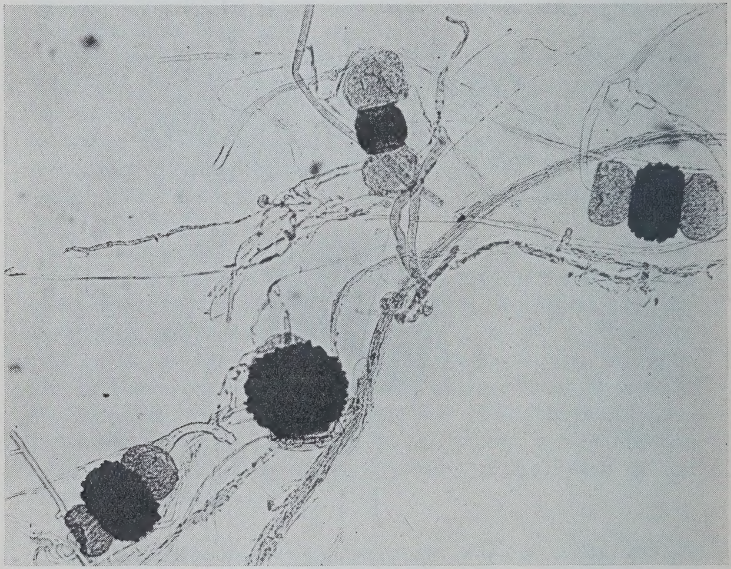

Fig. 32. *Sexual reproduction of* Mucor: photograph taken through the microscope showing four stages in the formation of black zygotes between the swollen ends of threads. (C. G. C. Chesters.)

mouldy. Spores fall on it and grow out into the threads of a new mould plant.

Less often *Mucor* reproduces in another way. Short branches grow club-shaped ends. Two such knobs come together and join (Fig. 32). This is called *conjugation.* Where the two branches have joined, a round ball is formed between the knobs. It is called a *zygote.* The zygote has a thick wall which is dark coloured and spiky. After a time, when the *Mucor* plant dies through being dried up or having no more food, the zygote comes free. The thick wall protects it from drying up, and later on, when the air is damp again, a new *Mucor* plant will grow out from it.

Conjugation and its result is *sexual reproduction.* Whenever two parts of a plant or an animal fuse together and from their union a new generation is produced, this is sexual reproduction. The formation of sporangia and spores is *asexual reproduction.* Here there is no union. The division into two by *Amoeba* or bacteria and the budding of yeast is also asexual reproduction.

Notice that the zygote of *Mucor*, like the spores of bacteria, is the *resting stage* of the plant. The thick cell wall resists drying up. The spores of *Mucor*, like the division of bacteria into two, are the method of multiplying or *increasing the number* of plants.

FUNGI. *Mucor* belongs to the group of colourless plants called Fungi. There are many different kinds of these. Some are greenish blue moulds (the colour is not chlorophyll) such as the fungus growing in gorgonzola cheese. The *mushroom* is another fungus. The whole of the mushroom plant is not seen unless you look for it. Much of it consists of threads like *Mucor,* living below the ground in manure and in humus, which, as you know, is made of decaying plants. The part which we eat bears the spores. If you leave the head of a mushroom for a day on a sheet of paper the spores fall out and you can see them (Exp. 7).

## PRACTICAL WORK

*Exp.* 1. Examine yeast in water under the microscope. It can be purchased at the nearest bakery.

*Exp.* 2. Grow yeast in a test-tube in a solution made up as follows: peptone 1 gram, maltose 5 grams, potassium phosphate 0·3 gram, magnesium sulphate 0·5 gram, in 1 litre water. Keep the culture in a warm place. Instead of the above solution, a 2 per cent. solution of malt extract bought at a chemist's may be used. Fit a bored cork to the test-tube with a bent tube leading into lime water. The latter will turn milky, showing that carbon dioxide is formed, and alcohol can be smelt in the test-tube.

*Exp.* 3. Examine the bacteria from a hay infusion under a high power of the microscope.

*Exp.* 4. Look at the nodules on the roots of a plant of the pea family.

*Exp.* 5. Make diagrams to illustrate the circulation of nitrogen and of carbon in nature.

*Exp.* 6. Cultivate *Mucor* on horse dung, on sliced tomatoes, or on stale bread which has been damped. The culture must be kept damp and warm. Examine the mould with a lens, looking for sporangia and zygotes.

*Exp.* 7. Mushrooms: explanation in text.

## *CHAPTER VIII*

# THE LOWER GREEN PLANTS

So far we have studied green plants which have leaves, stem and roots, and colourless plants having a very much simpler structure. There are also numerous simpler green plants. Examples of these are the *green scums* on ponds, *seaweeds, mosses* and *ferns*. These may be called lower, and plants like a buttercup or a tree higher green plants. Seaweeds, pond scums and *Chlamydomonas*, which we shall study next, are grouped together as Algae.

### I. *CHLAMYDOMONAS*

This plant lives in ponds containing farmyard refuse. It is a *single cell* of microscopic size and it swims about (Exp. 1). Fig. 33 A, shows its shape. The cell is surrounded by a cellulose cell wall. It swims actively by the lashing of two long cilia at its front end. Inside is a single basin-shaped green *chloroplast* (see p. 68). Hidden in the protoplasm within the basin there is a *nucleus*. At the front end are a red spot and two *contractile vacuoles* (see p. 43).

*Chlamydomonas* feeds like a higher green plant. That is to say, it absorbs carbon dioxide, and makes glucose and starch by photosynthesis. The carbon dioxide is of course in solution in the water surrounding the plant. From the water it also absorbs nitrates, and, joining these to glucose, builds up its proteins.

REPRODUCTION. There is both asexual and sexual reproduction.

In the *asexual reproduction* the cell first stops swimming and draws in its cilia. The nucleus divides into two and then the whole protoplasm, including the chloroplast, divides. There are now two cells inside the old cell wall (Fig. 33 B). Each new cell makes itself a new cell wall and grows cilia. Then the daughter cells break out of the old cell wall of the mother, swim away and grow to full size. This is really like the reproduction of *Amoeba* or bacteria. Often each daughter cell divides again before cilia are formed. Then four small cells swim out of the cell wall of the original mother cell (Fig. 33 C, D).

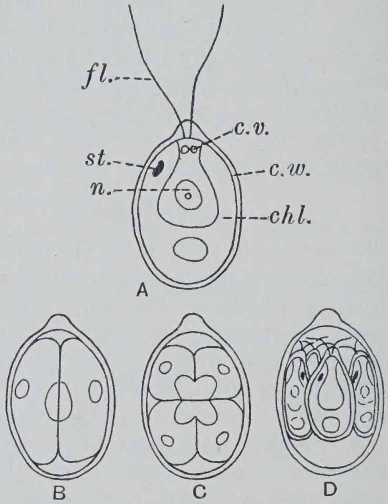

Fig. 33. *Chlamydomonas.* A is a swimming cell. *c.w.* cell wall; *fl.* cilium; *n.* nucleus; *chl.* chloroplast; *c.v.* contractile vacuole; *st.* red spot. B–D, stages of division into four new individuals.

In *sexual reproduction* the cell divides into two daughter cells and these divide again several times, so that a number of small cells swim out. They are called *gametes*. The gametes then unite together or *conjugate* in pairs. They join by their front ends, slipping out of their cell walls (Fig. 34). The nuclei of the two gametes join to form a single nucleus. The result of the conjugation is a *zygote* (compare *Mucor*).

The zygote makes itself a thick cell wall. As in *Mucor* it is the *resting stage* and can stand being dried. In this way

*Chlamydomonas* survives if the pond dries up. Later on the zygote divides and forms two or four ordinary cells with cilia, which swim off.

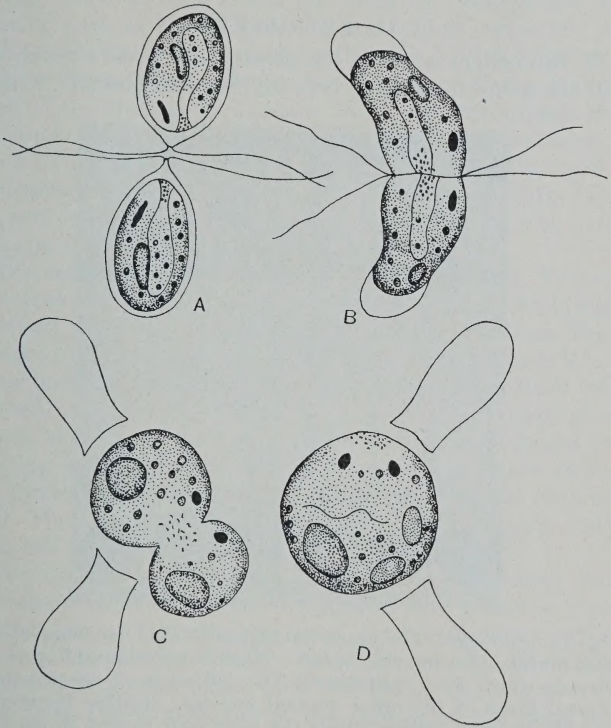

**Fig. 34.** *Conjugation of* Chlamydomonas. A, gametes approaching; B and C, stages of fusion; D, zygote.

In some kinds of *Chlamydomonas* all the gametes are of the same size. But in other kinds they are of two sizes, large and small. The large gametes are formed from one mother cell, the small ones from another. In conjugation a large gamete always unites with a small one. Two large gametes do not fuse, nor two small ones. The small gametes are called *male*, and the large gametes *female*.

## II. *SPIROGYRA*

If you collect some of the green scum from a pond, you will often find it made of very fine hairs or threads. One of the commonest kinds of these plants is *Spirogyra*. Under the microscope the threads are seen to be *unbranched* and made of *long cells* end to end (Fig. 35 and Exp. 2). Inside the protoplasm of each cell there is a green spiral ribbon. This is the *chloroplast*. It is spiral instead of being round as

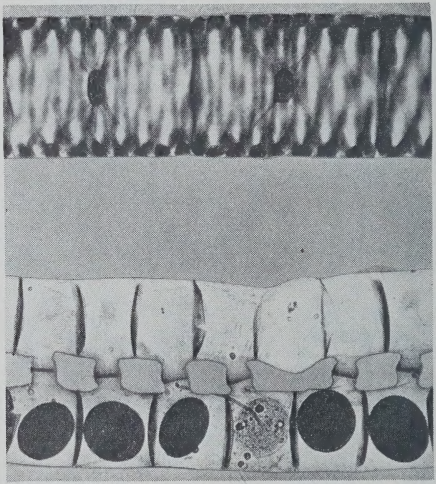

Fig. 35. *Spirogyra*. The upper photograph shows two complete cells with nuclei and spiral chloroplasts. The lower photograph shows two threads which have conjugated. The cell walls of one thread are empty, those of the other contain zygotes. Bridges between the threads are seen, across which the male cells moved to conjugate with the female cells. (W. Leach.)

in the cells of leaves, or basin-shaped as in *Chlamydomonas*. Having chlorophyll, *Spirogyra* feeds just like other green plants.

The inside of each cell is not filled by protoplasm. The greater part of the protoplasm is a lining inside the cell wall, while the middle of the cell is filled by a solution of salts in water. This solution is called the *cell sap* and the space it occupies is the *vacuole*. The spiral chloroplast is in the outer lining of protoplasm. The *nucleus* is sometimes in the centre of each cell. It is surrounded by a thin layer of protoplasm which is suspended from the main outer layer by protoplasmic strands. You can see this in the living cell and in Fig. 35.

The *sexual reproduction* of *Spirogyra* is curious. You can sometimes find the threads joined side by side with bridges between those cells which are opposite one another. These bridges have grown out from the cells of two threads which happened to be near together. When the bridges have been formed, all the contents of the cells of one thread move across them into the other thread. Then one thread has nothing left but empty cell walls, while the other thread has two lots of protoplasm and two nuclei within each cell wall. The two nuclei fuse, and so a *zygote* is formed inside each cell wall of one thread (Fig. 35).

The cells of the two plants that joined together were *gametes*, since they produced zygotes. The gametes which moved across the bridges were *male* and those which received them were *female*. As in *Mucor* and *Chlamydomonas*, the zygotes form thick cell walls. Then they come loose from the thread, fall to the bottom of the pond and can resist drought. Later on each zygote grows into a new *Spirogyra* thread.

## III. LIVERWORT

In damp places near waterfalls or in marshes, and also in greenhouses, there are small green plants called liverworts. *Pellia* is the name of one of them (Exp. 3). It is flat and tufted (Fig. 36). *Pellia* can grow only where the air is damp, for it has no thick cuticle (see p. 69). But if it gets dried up it can remain alive in the dry condition, and when wetted again it takes up water and resumes active life.

The body of the plant has *neither stem nor leaves.* All the cells are alike, except that underneath there are long cells resembling root hairs. These are called *rhizoids.* They absorb nitrates and other salts in solution from the ground, while the green cells take in carbon dioxide from the air. *Pellia,* then, although it is very much simpler than a higher plant such as a wallflower, is a step ahead of *Spirogyra.* Instead of all the cells being alike there are two kinds, one for absorbing salts, the other for photosynthesis. And there is another advance on *Spirogyra.* In sexual reproduction all the cells of *Spirogyra* could become gametes, but *Pellia* has special cells set apart for this purpose. There are male organs and female organs to produce the gametes. Both kinds of organs are on the same plant.

SEXUAL REPRODUCTION. The *male organs* (Fig. 36) produce numerous male gametes, called *spermatozoids* (Fig. 37). Each spermatozoid is a single cell, of a spiral shape, which has two *cilia* at its front end. It can swim actively in water by means of the cilia. The *female organs* are flask-shaped (Fig. 38). Inside each is a single female gamete, the *egg cell.* When there is rain water on the plant and the male organs are ripe the latter burst and the spermatozoids swim out. The female organs produce a chemical substance which attracts these spermatozoids. The spermatozoids swim down the neck of the female organ and one spermatozoid unites with the egg cell. The nucleus of the spermatozoid fuses with the nucleus of the egg. The result of the fusion of the two gametes is the *zygote*.

Fertilization. You notice that the male and female gametes are less like one another than they were in *Chlamydomonas* or *Spirogyra*. The spermatozoid is small and can swim so that it may reach the egg. The egg does not swim and it is larger because it contains a store of food for its future growth. The male gametes are very numerous, thus at least one may get to each female gamete. But there is only one egg cell in each female organ, for it is expensive for the plant to stock these cells with food. The union of spermatozoid and egg is called *fertilization*. It is

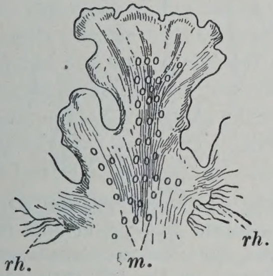

Fig. 36.

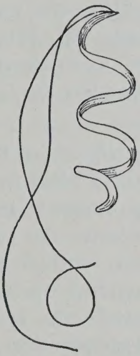

Fig. 37.

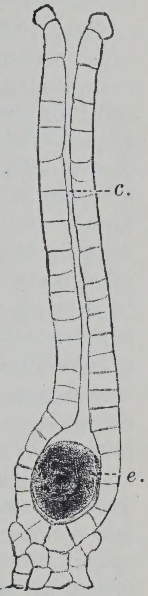

Fig. 38.

Fig. 36. *Pellia.* Plant seen from above. *m.* male organs; *rh.* rhizoids.

Fig. 37. *Spermatozoid of a liverwort* as seen under the microscope, showing the spiral shape and two long cilia.

Fig. 38. *Female organ of a liverwort.* This is an enlarged drawing of a section cut through the female organ. The egg cell (*e.*) is seen, and the canal (*c.*) down which the spermatozoid swims to fertilize the egg.

really the same thing as *conjugation*, but this word is kept for cases when the gametes are less unlike one another, as in *Chlamydomonas*, *Spirogyra* or *Mucor*.

BODY AND GAMETES. You notice also that in *Pellia* only certain cells of the plant become gametes. They cannot all do so as in *Spirogyra* or *Chlamydomonas*. In *Pellia* most of the cells are unable to reproduce and form new plants. They are bound to die in time. But with luck the reproductive cells, the gametes, can live on into another generation. We saw the beginning of this difference between plant body and reproductive cells in *Mucor*. Only the ends of certain threads of *Mucor* became gametes and formed zygotes: the rest of the threads eventually died.

SPORES. The zygote, or fertilized egg cell, of *Pellia* does not grow straight away into another *Pellia* plant. It produces a structure called the *sporogonium*, within which spores are formed. A stalk grows up into the air with a *capsule* on its top (Fig. 39). In this capsule numerous spores are formed. When ripe the capsule splits into four quarters like a star and the spores are scattered. Each of the spores can then grow into a new plant. The production of spores is called *asexual reproduction*.

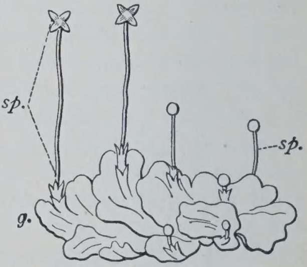

Fig. 39. *Pellia*. The plant (*g*.) bears the sporogonia (*sp*.). On the right the sporogonia are young, on the left their capsules have opened, liberating the spores.

ALTERNATION. The liverwort reproduces both sexually and asexually. So did *Mucor* and *Chlamydomonas*. But there is a difference. In the liverwort the zygote is always followed by spore formation. Asexual reproduction always follows on sexual. Then the spores grow into fresh liverwort plants, which again produce zygotes and then spores, and so on. In other words, sexual reproduction *alternates* with asexual. This was not so with *Mucor* and *Chlamydomonas*. Sometimes they reproduced sexually, sometimes asexually, but there was no order about it.

## IV. MOSS

Moss plants have *leaves* and *stem* as well as structures resembling root hairs called *rhizoids* (Fig. 40 and Exp. 3), yet there is none of the complicated structure you saw in the higher plant. The leaves, for instance, consist of just a single layer of cells, nearly all of them alike.

SEXUAL REPRODUCTION. The moss plant has *male and female sexual organs*. The male organs (Fig. 41) are on the ends of branches surrounded by leaves. Each male organ produces numerous male gametes, the *spermatozoids*. These are single cells of a spiral shape which can swim in water by means of two cilia. The flask-shaped female organs have a single female gamete or *egg cell* in the centre of each. They are very like the female organs of the liverwort (Fig. 38). In wet weather the male organs let loose the spermatozoids. These are attracted by a chemical substance produced by the female organs and they swim down the neck of the latter. One spermatozoid then unites with the egg cell. The process is called *fertilization*. It is really the same as conjugation in *Mucor*, *Chlamydomonas* or *Spirogyra*, but in the moss the two gametes which fuse are unlike one another. You will remember that this was the case also in certain kinds of *Chlamydomonas*.

SPORES. The fertilized egg, the *zygote*, does not develop directly into a new moss plant. It grows first into a spore-producing structure, called the *sporogonium*. The sporogonium consists of a stalk with a swollen organ, the *capsule*, on top. These can very frequently be seen on moss plants (Fig. 40). Inside the capsule, the *spores* are formed. There is a *lid* which comes off when the spores are ripe. When the lid is off you can see a ring of *teeth*. They consist of

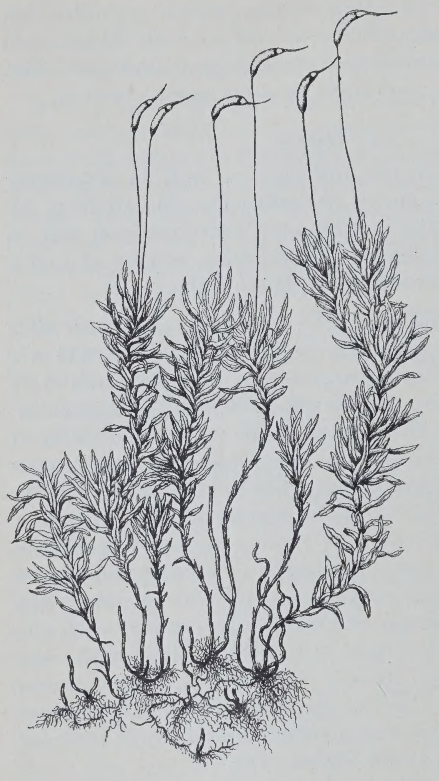

Fig. 40.

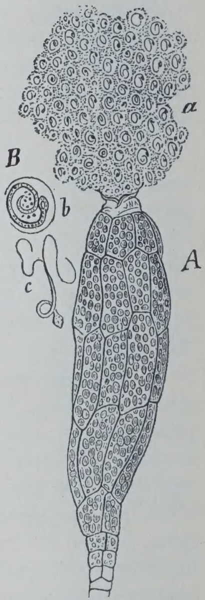

Fig. 41.

Fig. 40. *Moss plants* with stems, leaves and rhizoids. This is the sexual generation. The asexual generation, consisting of the stalked sporogonium, can be seen at the top of the picture.

Fig. 41. *Male organ of a moss. A* is an enlarged drawing of the male organ bursting and letting out the spermatozoids (*a*). *B* shows a spermatozoid (*b*) before it becomes free, and one liberated (*c*) swimming by its two cilia.

thickened cell walls of dead cells. These teeth change their shape in wet and dry weather. When it is wet they close down, while in dry air they open out. In this way the spores can escape only in dry weather. Then the spores are blown about by the wind and so are spread from place to place. Later on the spores grow into new moss plants.

BODY AND GAMETES. There are great differences between the moss and *Spirogyra* or *Chlamydomonas*. Not only is the moss divided into different kinds of cells, each with different functions, but there is another great distinction. In *Chlamydomonas* and *Spirogyra* all the cells could form gametes and so could live on into another generation. But in the moss only a few cells can do this. Most cells of the body are bound to die, while a few, if fortunate, can continue to live and multiply to form another plant.

ALTERNATION. The moss reproduces both sexually and asexually. This is the case, too, with *Chlamydomonas* and *Mucor*. But in the moss sexual reproduction is always followed by asexual. The one alternates with the other. In *Chlamydomonas* and *Mucor* there is no such regular order.

## V. THE FERN

*Chlamydomonas* and *Spirogyra* are lower green plants living in water. The fern lives on land and has arrangements to prevent too much loss of water (see p. 69). In *Spirogyra* all the cells are alike, but the fern has *leaves*, *stem* and *roots* like a higher plant such as the wallflower. The cells that make up these different parts of the fern plant are not alike. Each kind has its particular function. Photosynthesis goes on in the green leaves, and so does transpiration. Salts dissolved in water are absorbed by the roots. And since the different kinds of cells are separated from one another, there are *vascular bundles* to convey solutions from one part of the plant to another.

The shape of fern *leaves* or *fronds* is known to everyone. The *stem* is down on the ground, and in some ferns, such as

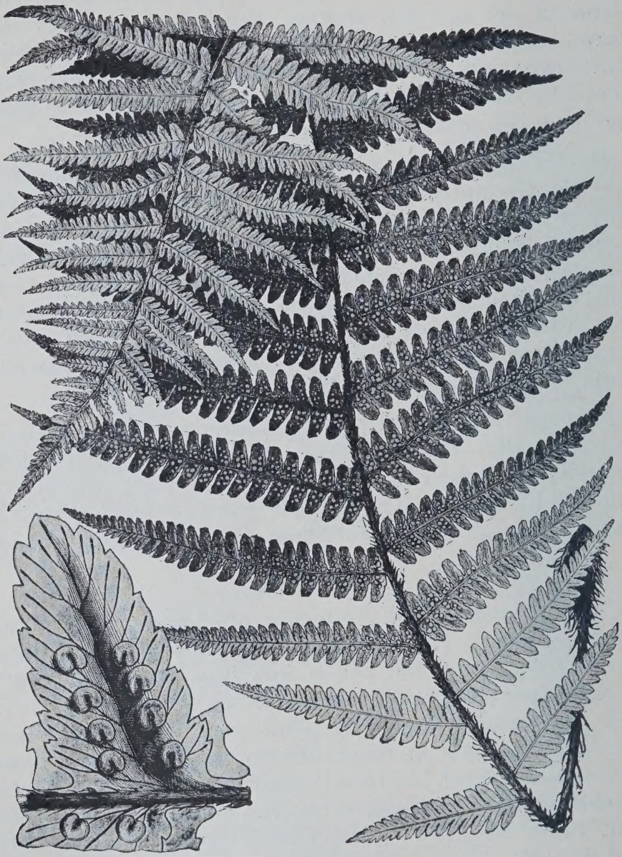

Fig. 42. *Leaf of fern*. The small round objects on the leaf are the covers of the groups of sporangia. On the left is a portion of the leaf magnified. The covers of the sporangia are seen to be kidney-shaped.

bracken, there are spreading underground stems. These continually send up new leaves, while the older parts of the stem die off. In this way the fern spreads to new ground.

Asexual reproduction. On the under side of the leaves are small brown bodies. These are groups of *sporangia* (Fig. 42) which form *spores*. Each group of sporangia is hidden by a brown cover. By taking this off with a needle you can see the sporangia (Exp. 4). If you now look at a sporangium with a microscope you will see it is shaped like a lens. The cells marked *A* in Fig. 43 are dead. In dry weather, after the spores have ripened, the curved row of cell walls straightens out and tears the sporangium at *B*. Then the spores are shot out by the recoil of the

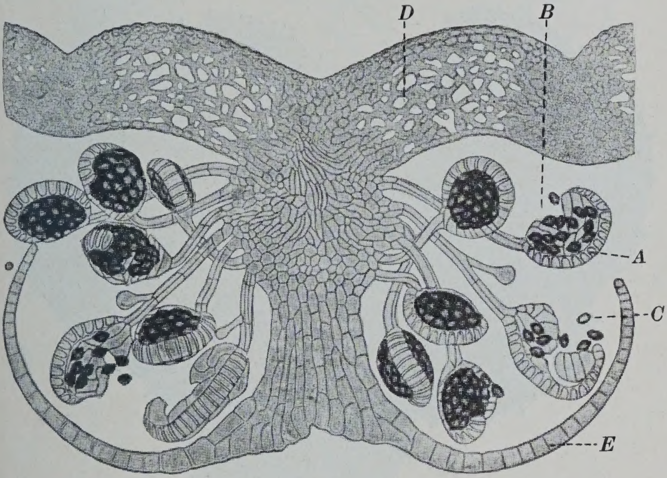

Fig. 43. *Group of sporangia on the leaf of a fern cut through the middle.* *A*, ring of dead cells on the wall of a sporangium; *B*, place at which the sporangium tears open; *C*, spore; *D*, leaf; *E*, cover of group of sporangia.

spring *A*. Each spore is a single cell with a nucleus. They can be blown a certain distance by the wind.

PROTHALLUS. If the spore falls in a damp warm place it grows, dividing first into two cells and then into four and so on. But the result of this is not another fern plant such as you are familiar with. A small flat green plant results, called a prothallus (Fig. 44), measuring about $\frac{1}{4}$ inch across. It is heart-shaped and has *rhizoids* (resembling root hairs) on the lower side. You can find prothalli on damp shaded ground near fern plants (Exp. 5). The prothallus has a much simpler structure than the fern plant. It just has green cells for photosynthesis, and rhizoids. In addition there are sexual organs.

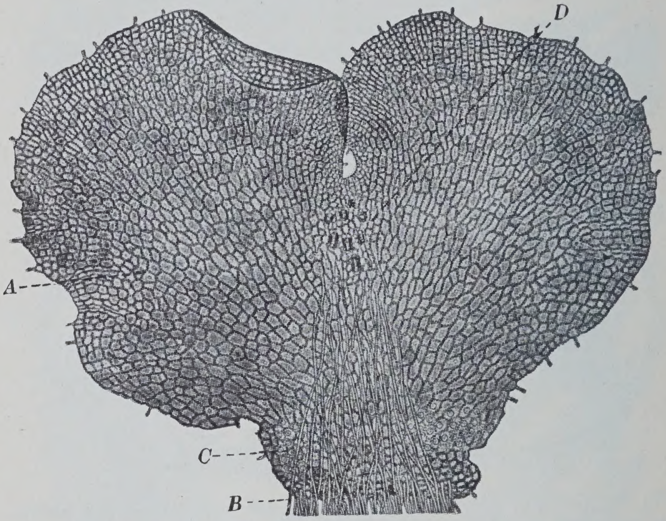

Fig. 44. *Fern prothallus* seen from underneath. *A*, cells of prothallus; *B*, rhizoids; *C*, male organs; *D*, female organs.

Sexual reproduction. The fern plant reproduces asexually by its spores. The prothallus reproduces sexually. On the lower surface are very small *male organs* and *female organs* (Fig. 45). These produce the *gametes*, which are not all alike. They are male and female as in some kinds of *Chlamydomonas*. The *male gametes* are spiral and have numerous *cilia* for swimming (Exp. 6). They are called *spermatozoids*. A large number of them are formed in each male organ. A spermatozoid is a single cell and most of it is occupied by the nucleus: there is little other protoplasm in it.

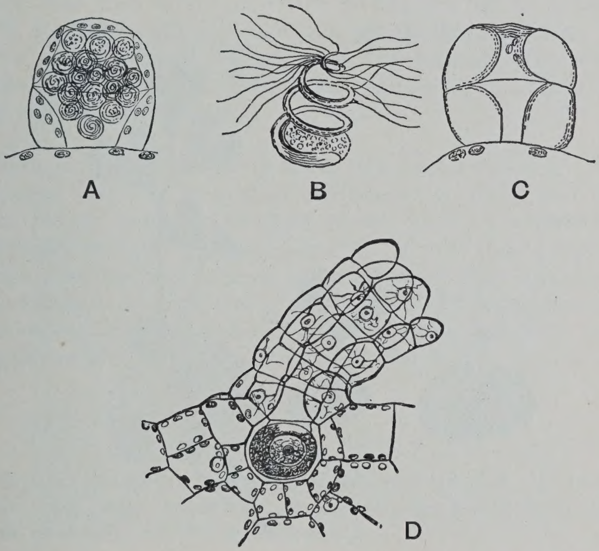

Fig. 45. *Sexual organs of fern prothallus.* A, male organ containing spermatozoids. B, a spermatozoid drawn on a larger scale. C, male organ, empty, after the spermatozoids have come out of it. D, female organ containing one egg cell. There is a passage from the tip of the female organ down to the egg cell.

FERTILIZATION. A *female organ* of a prothallus is shown in Fig. 45. It has one gamete inside it, the *egg cell.* When there is a film of rain water on the prothallus the spermatozoids swim out of the male organs. They are attracted to the female organs by an acid which these produce. The spermatozoids swim in through the entrance of the female organs. The most active spermatozoid, but a single one only, fuses with the egg cell in each female organ and their nuclei unite. This is called *fertilization of the egg.* It is really the same thing as *conjugation* in *Mucor*, *Chlamydomonas* and *Spirogyra*, but when the two gametes are so very unlike one another the word "fertilization" is used.

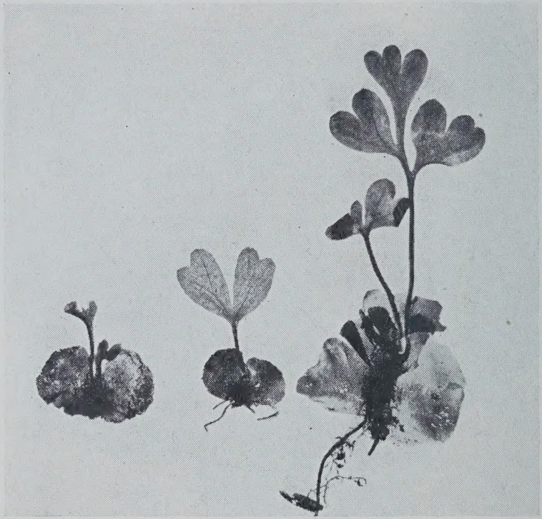

Fig. 46. *Prothalli and young fern plants.* Three prothalli each with a young fern plant developed from a fertilized egg cell. The roots of the fern plant on the right are seen. (W. Leach.)

The spermatozoid is very small and can swim. Thus it may reach the egg. The egg is larger and cannot move because it contains reserve food for the young plant into which it will later on develop. There are very many spermatozoids compared to the number of eggs to make sure that one of them shall find each egg. When an egg cell has been fertilized, it grows, not into another prothallus, but into the familiar fern plant. Fig. 46 shows young fern plants attached to prothalli. Each has developed from a fertilized egg cell in the prothallus.

SEXUAL AND ASEXUAL GENERATIONS. You see now that the prothallus reproduces sexually and new fern plants result. The fern plant in turn reproduces asexually and prothalli are formed. There is thus a regular series of sexual and asexual generations, as they are called, *alternating* one after another. *Mucor* and *Chlamydomonas* also reproduce both sexually and asexually, but there is no regular order about it as there is in the fern.[1]

## PRACTICAL WORK

*Exp.* 1. Examine living *Chlamydomonas* under the microscope. *Chlamydomonas* can most easily be found in shallow pools or ponds containing farm refuse.

*Exp.* 2. Study *Spirogyra* under the microscope.

*Exp.* 3. Examine *Pellia* or a moss with a lens and look for reproductive organs.

*Exp.* 4. Look at the different parts of a fern plant and examine the sporangia with a lens.

*Exp.* 5. Examine a prothallus with a lens and look for male and female organs.

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[1] The prothallus (sexual generation) corresponds to the liverwort plant or the moss plant. The fern plant (asexual generation) corresponds to the sporogonium in liverwort or moss.

*Exp.* 6. Put some fine soil in a flat dish with a glass cover, add enough water to make it damp, and sow fern spores on the surface. Leave the dish for three or four months, taking care that the soil does not become dry. Prothalli will grow from the spores. When they are large mount several upside down in water on a microscope slide and look for the male and female reproductive organs. Spermatozoids may be seen swimming out of the male organs and being attracted by the female organs.

## *CHAPTER IX*

# *HYDRA* AND WORMS

THE animals about which you have learnt already are human beings, frogs, and *Amoeba*. The first and the last are the extremes of animal life. *Amoeba* is formed by one cell only, which carries on all the activities of life. Our own bodies are made up of countless cells, which are of a number of different kinds. Each kind has its own particular task to do, the cells of each kind are grouped together to form tissues, and a number of tissues make up organs. There is thus a division of labour among the different kinds of cell and the whole body is very complicated. We saw the same contrast between the lower and higher plants. Next we are going to study an animal that is certainly composed of a number of cells, but its structure is very simple indeed compared with the frog or man. This animal is *Hydra*.

## I. *HYDRA*

*Hydra* lives in ponds. It is small but you can easily see it with the naked eye (Fig. 47 and Exp. 1). There are two kinds (species), one of which is green and the other brown. The body is at one time long and narrow, at another short and thick. It is attached by one end, the *base*, to a pond weed. At the other end, which often hangs downwards, are a number of fine threads called *tentacles*. Being attached to the weed, *Hydra* looks at first sight like a plant, but it is an animal. It can move slowly, creeping like a snail. It can also move in another way: sometimes the base comes free and the *Hydra* walks along the ground by what is called a looping motion, like some caterpillars. If *Hydra* is touched, the tentacles suddenly shorten to mere knobs and at the same time the body becomes shorter and thicker.

*Hydra* has a *mouth* which is in the middle of one end, between the tentacles. The mouth is the only opening into the inside of the body. The internal structure of the animal is extremely simple. There is just a *stomach* into which the

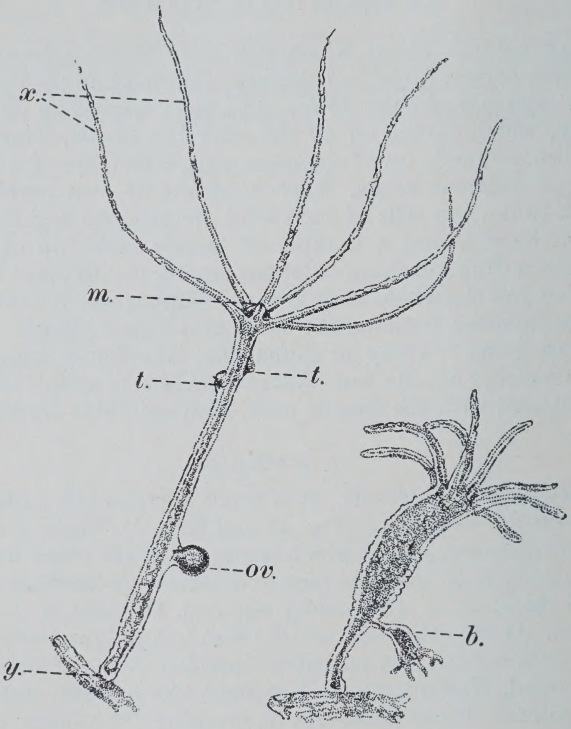

Fig. 47. *Hydra.* The animal on the left is fully extended, that on the right is half extended. *b.* bud; *m.* mouth; *ov.* ovary; *t.* testis; *x*, tentacles; *y*, base.

mouth opens. The stomach is simply surrounded by the wall of the body. *Hydra* feeds by catching small animals swimming in the water. When, for example, a "water flea"[1] touches one of the tentacles, this sticks to it. The other tentacles close round the prey, which is drawn into the mouth. It is then swallowed, digested, and the indigestible remains are thrown out again through the mouth.

INNER LAYER OF CELLS. *Hydra* is really nothing but a sort of little bag made of cells. There are no organs.

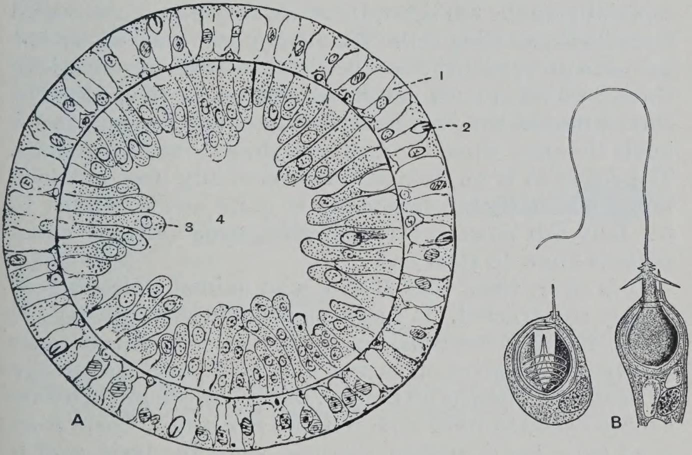

Fig. 48. *Structure of* Hydra. A, section across the middle of the body, seen under the microscope; 1, outer layer of cells; 2, a thread cell; 3, inner layer of cells; 4, stomach. B, a thread cell further magnified. On the left, the thread is coiled inside the cell; on the right, the thread has been shot out.

The cells are arranged in *two layers* (Fig. 48), an outer and an inner, the latter lining the stomach. The cells are not all alike; there is a certain amount of division of labour among them, but there are fewer different kinds of cells than in ourselves. Surrounding the stomach are some cells which act as *glands*, preparing the digestive enzymes. And there are others which *absorb* the digested food.

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[1] *Daphnia*, see p. 224.

OUTER LAYER OF CELLS. In the outer layer most of the cells act at the same time both as the "*skin*" and as *muscle cells*. Here, then, is only a partial division of labour. There are *nerve cells* too. These give the signal, when the animal is touched or when a water-flea is caught, for the muscle cells to contract. But there are no eyes or ears, nor is there anything like a brain. In the outer layer, and especially on the tentacles, there are very peculiar so-called *thread cells*, or sting cells. When they are touched by the animal's prey, each of these cells suddenly shoots out a long thread which is both poisonous and sticky (Exp. 2). The thread numbs the prey so that it does not struggle and it holds the prey while the tentacles drag it into the mouth. The *jelly-fish* is an animal which certainly does not look much like a *Hydra*, but really is quite nearly related to it. Jelly-fish possess very powerful sting cells, as many bathers know to their cost.

It is clear, then, that *Hydra* is an animal which is very simply constructed. It has a mouth and stomach but no anus. It has nerve cells, but no nerves or brain. It takes in oxygen and gives off carbon dioxide all over the surface of the body. There is no kidney, but the waste products are simply excreted from each cell into the water. There is no need for a blood system, because, since the body wall is only two layers of cells thick, there is no distance to carry oxygen, or digested food, or waste matters.

REPRODUCTION. *Hydra* reproduces its kind in two ways. There is both *asexual* and *sexual* reproduction. In the first method *buds* are formed, in the second *eggs*.

Let us take the *budding* first. You can often see a *Hydra* with a small one sticking on to its side. This is a bud (Fig. 47). At first it was a mere pimple on the parent's body. Then it has tentacles and a mouth, but its stomach still opens into the parent's stomach. Later on, the bud will get cut off by a base, and it will then drop off and start life as a new individual. Sometimes several buds can be seen at the same time growing out from one parent.

SEXUAL REPRODUCTION. When *Hydra* reproduces sexually there are not separate male and female individuals, as in higher animals or in *Spirogyra*. A single individual *Hydra* is both male and female at the same time, like a liverwort, a moss, or a fern prothallus. Animals which bear both male and female organs in the same individual are said to be *hermaphrodite*. When a *Hydra* is reproducing sexually, bumps are seen sticking out on the body wall. Those nearer to the base are the female organs, or *ovaries*. Those closer to the tentacles are the male organs, or *testes* (Fig. 47). Inside the ovary is a single *egg cell*. It is round and larger than the other cells of the body, and as usual it has a nucleus in it. The testis is made of many small cells. Each of these develops into a *spermatozoon*, which is not unlike the spermatozoids of *Pellia*, the moss, or the fern. After a time the wall of the testis bursts and the spermatozoa all swim out into the water. The spermatozoa of most animals (Fig. 49) consist each of a "head" and a long "tail". The "head" contains the nucleus which almost fills it up. The "tail", which is something like a cilium (p. 45), is for swimming. It lashes the water violently and moves the spermatozoon along head first (Exp. 3).

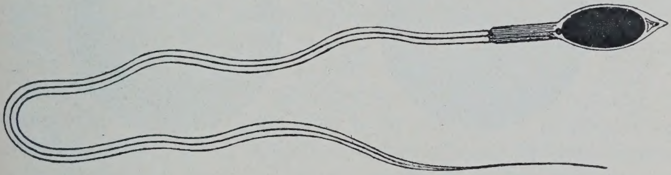

Fig. 49. *Spermatozoon* magnified 4,000 fold. The nucleus is shown in black. The tail is drawn bent on itself to save space.

FERTILIZATION. The egg cell cannot grow into a new *Hydra* individual until a spermatozoon has united with it. When one of the spermatozoa swimming in the water meets an egg cell, which when ripe sticks out of the ovary of *Hydra* but is still attached to it, then the spermatozoon penetrates into the egg.

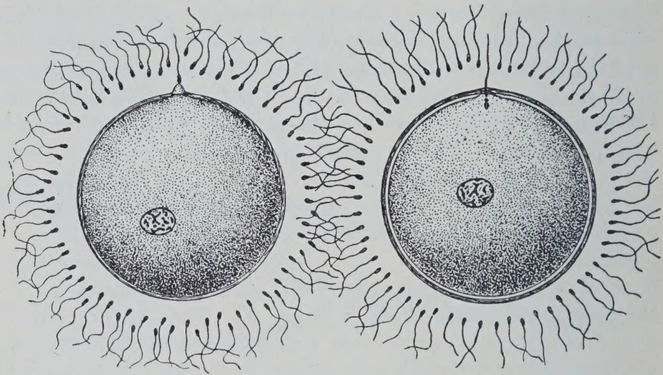

Fig. 50. *Fertilization*. Eggs of a marine animal, the sea-urchin, are seen surrounded by spermatozoa. The spermatozoa are attracted to the egg by a chemical substance given off into the water by the egg. One spermatozoon is seen penetrating into the egg. The egg has a nucleus in the middle of it which will unite with the nucleus of the spermatozoon.

Fig. 50 shows eggs of a marine animal, the sea-urchin, surrounded by spermatozoa. The sea-urchin itself is seen in Fig. 108. Eggs and spermatozoa are shed by female and male sea-urchins into the sea water. There spermatozoa unite with the eggs. In the case of the sea-urchin, of *Hydra*, and of all other animals, when one spermatozoon gets in, a change happens in the surface of the egg, so that no more spermatozoa can enter. The next thing that occurs is that the nucleus of the spermatozoon unites with the nucleus of the egg cell. This is the process of fertilization. Only after it has happened can the egg develop into a new individual.

You see that the egg cell is much larger than the spermatozoon. This is because the egg contains a store of food material to nourish the young animal into which it will develop, until this can catch food for itself. Some eggs contain an enormous amount of food, as, for example, the hen's egg. This store of food is the *yolk*. Others have less yolk in them, as the eggs of *Hydra* and of the sea-urchin. The spermatozoon is small because it has no food reserve and also in order that it may swim actively and so find the egg. You see also that many more spermatozoa are produced than eggs, yet only one spermatozoon is needed for each egg. The excess of spermatozoa increases the chances of each egg being fertilized.

DEVELOPMENT OF THE FERTILIZED EGG. After the egg of *Hydra* has been fertilized, it does not develop immediately into a new individual. It next forms a thick shell around itself and drops out of the ovary on to the bottom of the pond. If the pond happens to dry up, then the race of *Hydra* is not killed off, for the egg inside its shell can resist being dried.

Later on, in the water at the bottom of the pond, the egg starts developing. The nucleus first divides into two and then the rest of the cell divides. You will remember that this is just what happened to *Amoeba* when it reproduced. But in the case of the egg, the two daughter cells do not come apart. They stick together. Then each of them divides again, so that there are now four cells. From these come in succession eight, then sixteen, thirty-two, sixty-four cells, and so on. The fertilized egg cells of all animals and plants divide in much the same way. Fig. 51 shows photographs of the cell divisions in the fertilized egg of the sea-urchin.

The cells are at first all alike, but when many of them have been formed by division they begin to be different from one

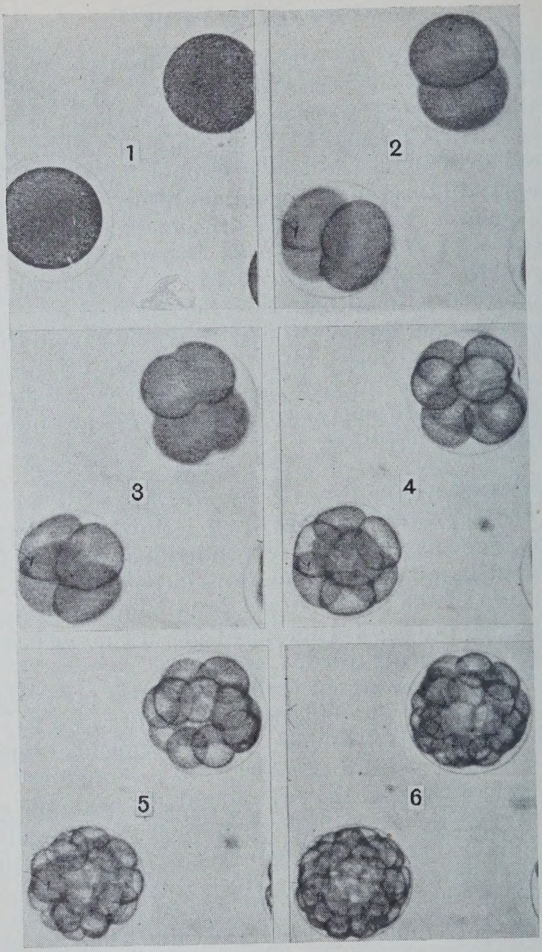

Fig. 51. *Cell division of fertilized egg.* Six photographs showing successive cell divisions of two fertilized sea-urchin eggs, taken under the microscope with a cinematograph camera. The time taken from fertilization to the first division (stage 2 above) is one hour at 20° C. (F. Vlès.)

another. In this way the various different kinds of cells of the full-grown animal appear. It is quite clear that every cell in the animal's body is a direct descendant of the original fertilized egg cell.

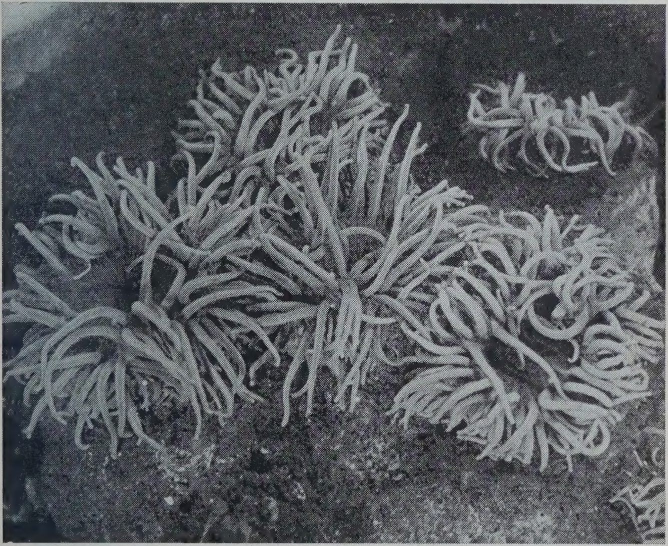

Fig. 52. *Living sea-anemones*. The mouth of the left-hand animal can be seen between the tentacles. The photograph was taken at the Plymouth Aquarium. (D. P. Wilson.)

REGENERATION. If a piece of the body of a *Hydra* is accidentally torn off, the remaining part can grow again into the whole. Suppose that the end with mouth and tentacles is cut off. Then the part with the base grows out a new end-part with mouth and crown of tentacles (Exp. 4). This power of replacing lost parts is called regeneration. Many animals have the power of regeneration. For ex-

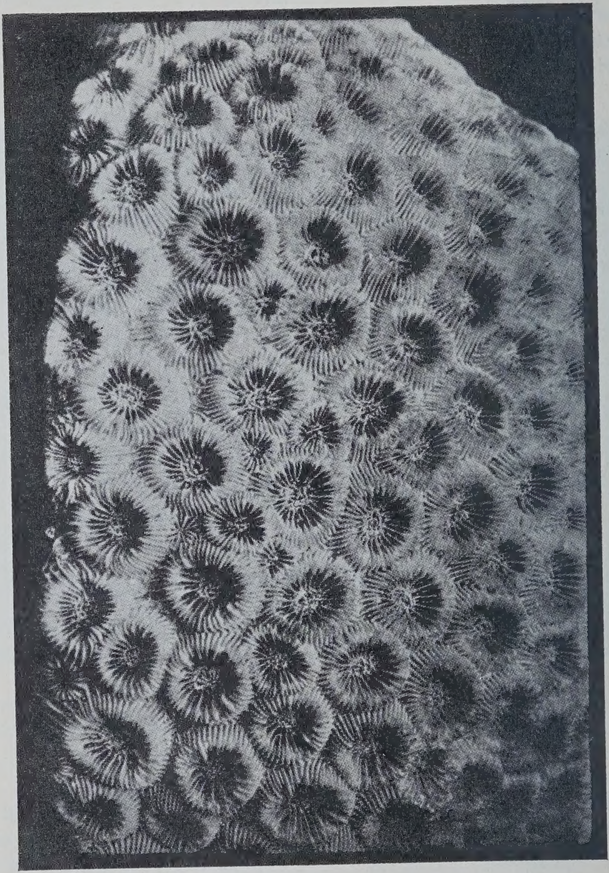

Fig. 53. *Coral*. The photograph shows the skeletons or shells of the individual coral animals.

ample, if you catch a lizard by its tail, the tail breaks off in your hand. Later on the lizard grows itself a new tail. Obviously, this power is of advantage to the lizard, for it gives it a much better chance of escaping from enemies, such as birds. The more complicated is the structure of an animal, the less power it has of regenerating lost parts. Our bodies can do no more than heal wounds.

CORAL. The *sea-anemone* which is so common in rock pools at low tide along our coasts is something like a big *Hydra* (Fig. 52). *Corals*, too, are very much the same kind of animals. Imagine a very large *Hydra* with a number of buds on it. Imagine further that the buds do not drop off. Then you have something like a coral, with this difference, however, that the coral cannot move about. It cannot do this because its base produces a skeleton made of calcium carbonate (Fig. 53). This is not an internal skeleton like our own, but an external skeleton like the shell of a snail. Corals are very common in the warmer seas of the world, where their skeletons are so abundant that they form reefs.

## II. THE EARTHWORM

The worm is quite a different sort of creature from *Hydra*. It has a much more complicated structure. If you look carefully at an earthworm you will see that its long body appears to be made up of rings joined end to end. These are called *segments*, and you will find that much of the inner structure of the worm is *segmented* in the same way.

From the outside the *mouth* can be seen on the lower surface between the first and second segments, and the *anus* on the last segment (Fig. 54 and Exp. 5). About one-third of the way from the front end some of the segments are thicker. These have microscopic glands in them which form a sticky substance that encloses the eggs of the worm in a sort of case when they are laid. If you now look at the worm with a lens you will notice small *bristles* on the sides of every segment. These give the worm a foothold on the ground as it moves forward. It does this by alternately contracting and relaxing the muscles of its body wall (Exp. 6).

SENSES. An earthworm has no eyes or ears. But there are nerve cells in the skin which detect touch and tremblings in the ground. If worms have come up out of their burrows on to the lawn on a wet morning, they vanish when your footsteps approach. The animal can also smell (Exp. 7), and although, of course, having no eyes it cannot see what its surroundings are like, yet it moves back when a bright light falls on it (Exp. 8).

SKIN. The earthworm's skin is always moist. It is kept damp by being covered with slimy *mucus* which attracts water. In the same way the frog's skin keeps moist. Just as in the case of the frog, it is necessary for the worm's skin to be damp, for its outer layer consists of living cells. If these cells dried up they would die. Our own skin has layers of dead cells on the surface. Thus our bodies do not lose water by evaporation in dry air. But the worm is almost an aquatic animal. It lives only in its damp burrows, or outside on

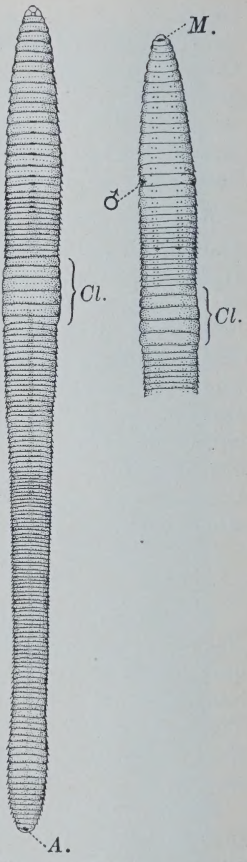

Fig. 54. *Earthworm.* Left figure, from the upper side; right figure, from the lower side. *M.* mouth; *A.* anus; *Cl.* thicker segments which produce the egg case; ♂, male opening.

a wet day. The earthworm *breathes* through its skin. It has no lungs. The gas exchange between air and blood, oxygen going inwards and carbon dioxide going out, can only take place through living cells. The earthworm is able to do this through its skin. But we ourselves have to keep the living cells for the gas exchange tucked away inside our bodies so that they shall not dry up. This, you know, is the reason for lungs.

FEEDING. If, now, you look at the body of a dead earthworm, which has been opened by a cut down the back, you will see its *alimentary canal* extending right along from the mouth to the anus (Fig. 55 and Exp. 9). The worm eats earth. Its digestive enzymes *digest* the microscopic animals and plants in the soil which it swallows and the indigestible earth is expelled through the anus. This forms the *worm castings* seen on a lawn. In the dissection *blood vessels* are visible which convey the digested food away from the alimentary canal. The blood is coloured with *haemoglobin* for the same reason that our own blood is red.

BODY CAVITY. Between the alimentary canal and the muscular wall of the body is a space filled with liquid. This is a *body cavity*, just as there is one in the frog and man. The body cavity is divided up by cross-partitions (*septa*) into compartments which correspond with the segments seen from the outside. The very obvious white structures inside the front end of the worm are the *reproductive organs*. Like *Hydra*, the earthworm is hermaphrodite, each individual having both male and female organs. In the body cavity in each segment there is a pair of small *excretory organs* corresponding to kidneys.

NERVOUS SYSTEM. The central nervous system of the frog (brain and spinal cord) lies towards the upper surface of the animal. It is above all the other organs. In the earthworm, on the contrary, the *nerve cord* is below the body cavity. It can be seen in a dissection after the

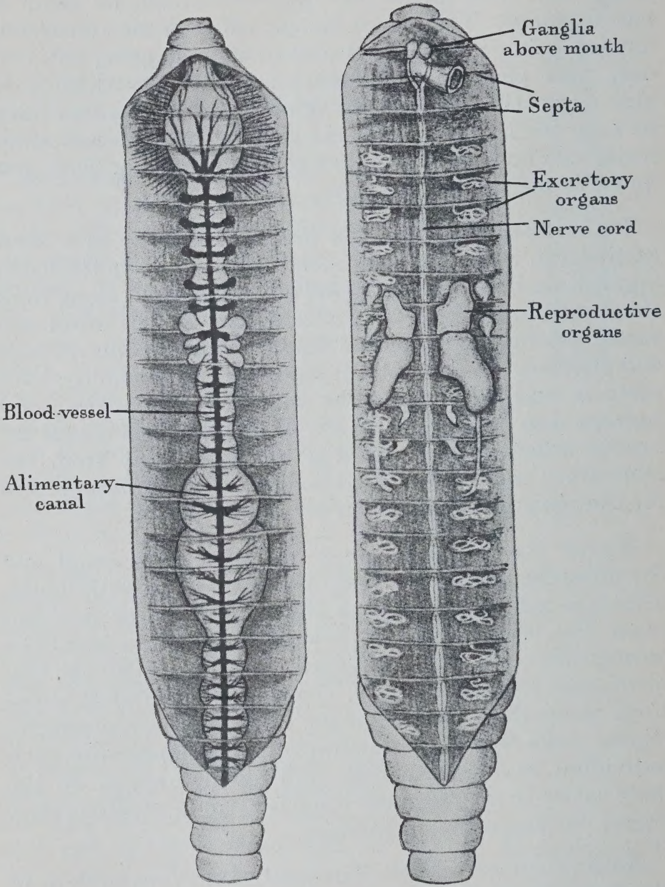
Ganglia above mouth
Septa
Excretory organs
Nerve cord
Reproductive organs
Blood-vessel
Alimentary canal

Fig. 55. *Earthworm* dissected from the upper surface. In the right-hand dissection the alimentary canal has been removed.

alimentary canal has been removed (Exp. 10). You will see a long white *cord* running from end to end of the animal, with a swelling, or *ganglion*, in each segment. The worm has not one single brain, like man, but each ganglion is a partial brain. At the front end the nerve cord divides into two. The branches pass up around each side of the alimentary canal and join again to a pair of ganglia above the mouth.

SEGMENTED ANIMALS. It is clear that the whole structure of the earthworm is segmented. From the outside the animal can be seen to be made up of segments which follow one another, each one being more or less like its neighbour in front and behind. Inside, the structure is similar. The body cavity is divided up into a long series of segments, and each segment has in it a ganglion and a pair of excretory organs. You have seen already that vertebrate animals, too, are segmented (p. 36), although their bodies are constructed on quite a different plan from that of the earthworm.

THE VALUE OF EARTHWORMS. In forming their burrows worms literally eat the earth. Earth is brought up to the surface of the soil as "worm casts". This fact is of great importance to the growth of plants. Earthworms are more numerous than one usually supposes, and Charles Darwin (Fig. 151) calculated that in a year they may throw up eighteen tons of earth per acre of land. After the soil has passed through the bodies of the worms it is finely divided and very suitable for the penetration of root hairs. Moreover, the burrows allow air to enter the soil and so supply oxygen for the respiration of roots. In addition, the soil does not become waterlogged, for surface water can drain away. And there is yet another service the worms render. They drag leaves into their burrows and thus the formation of humus (p. 65) is furthered.

MARINE WORMS. There are many different kinds of worms living in the sea. One of these is the common lugworm, *Arenicola*. It lives in sandy mud in the same way as the earthworm lives in soil. Its most obvious difference from the earthworm is that it has *gills* along the sides of the body (Exp. 11). *Nereis* is another common worm found at low tide. There are outgrowths (*parapodia*) on either side of each segment. These have long bristles and act like stumpy limbs. At the head end *Nereis* has *tentacles*, or feelers, and four *eyes*.

## PRACTICAL WORK

*Exp*. 1. Examine living *Hydra* with a lens. Note retraction when it is touched, and expansion again after an interval. Look for buds.

*Exp*. 2. When *Hydra* is examined with the microscope under a cover-slip some of the thread cells will put out their threads. This can be brought about readily by allowing methylene blue to diffuse in beneath the cover-slip.

*Exp*. 3. Demonstration under the microscope of living spermatozoa, taken from the genital duct of the pond snail *Limnaea* and mounted in a drop of the snail's blood.

*Exp*.4. Cut off the crowns of tentacles of several individuals of *Hydra*. In the course of a few days new tentacles are regenerated.

*Exp*. 5. Examine with a lens an earthworm that has been killed by immersion in hot water.

*Exp*. 6. Study the movements of an earthworm as it moves forward. If its front end is touched, it stops and moves backward.

*Exp*. 7. If a fine paint brush dipped into an essential oil or xylol is brought near an earthworm it moves. By bringing the brush near different parts of the worm in succession it can be shown which regions are most sensitive to smell.

*Exp*. 8. Put an earthworm into a glass tube just wide enough to hold it. Fit two cylinders of black paper end to end outside the tube. By sliding the paper cylinders along, the body of the worm can be concealed from light all but a narrow space between the cylinders. Light can now be focused on each region of the worm's body in turn and the reactions of the different regions to the light can be seen.

*Exp.* 9. Earthworm dissected to show the alimentary canal.

*Exp.* 10. Earthworm dissected to show the nervous system.

*Exp.* 11. Demonstration of *Arenicola* and *Nereis*.

## *CHAPTER X*

# INSECTS

INSECTS are the most abundant group of animals on the surface of the earth. About a million different kinds (species) of living animals are known to science and out of these nearly one-half are insects. We are going to study the cockroach first, because it is a fairly large-sized insect and is easy to get.

### I. THE COCKROACH

It is obvious at once that this is a *segmented* animal like the earthworm (Exp. 1). The two do not look very much alike at first sight, but you will find that in many important points they are built on the same plan, which is quite a different plan from that of the frog or man.

BODY. The cockroach is divided into three regions, *head*, *thorax* and *abdomen* (Fig. 56). The head has a pair of jointed feelers or *antennae*, and two large *eyes*. The antennae are always moving about, feeling the ground and smelling the air. The eyes are quite unlike our own. If you look at them with a lens you will see very numerous small *facets*. You will read later on how these eyes work (Chap. XVII).

The thorax bears three pairs of jointed *legs* and on its back two pairs of *wings*. The front pair forms a protecting case for the back pair. It is chiefly with the latter that the animal flies, on the rare occasions when it does fly. The back wings are folded under the front pair when at rest. (The females of one kind of cockroach have no wings.) The thorax has three segments, but they are joined together. The fact that there are three pairs of legs on the thorax shows that it really does consist of three segments. The abdomen is obviously segmented, each segment being attached flexibly to the neighbouring segments. At the end of the abdomen is a pair of jointed outgrowths.

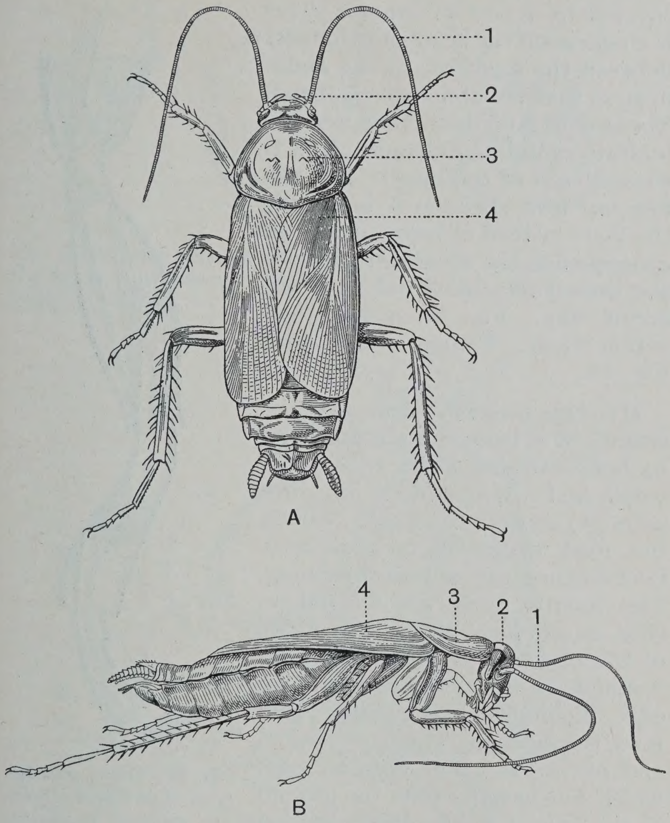

Fig. 56. *Cockroach.* A, top view; B, side view, twice natural size. 1, antenna; 2 (in A), palp of maxilla; 2 (in B), head; 3, thorax; 4, front wing.

SKELETON. The whole body of the cockroach is covered by a sort of armour. This is thickest on the head and thinnest between the segments of the abdomen, so that the abdomen can bend. The armour is made of *chitin*, a carbohydrate containing nitrogen. This is the skeleton of the insect. But unlike our own skeleton it is outside the body instead of being inside. In consequence, the muscles that work the limb joints must act in a different way. Fig. 57 makes their action clear. Compare this with Fig. 13.

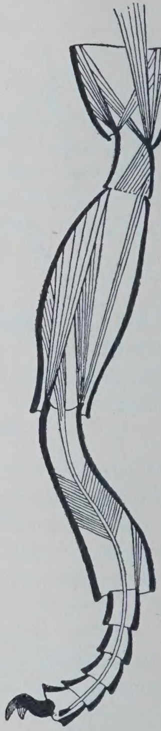

Fig. 57. *Insect muscles.* A leg of an insect is seen. The skeleton is outside the muscles. Note how the muscles are attached at the joints.

MOUTH PARTS. The head of the cockroach is bent at right angles to its body. On the lower edge is the *mouth* and just outside it are three pairs of mouth parts which tear up the food before it is swallowed. Cockroaches eat almost anything. The mouth parts are as follows (Fig. 58 and Exp. 2). On either side of the mouth is a powerful jaw or *mandible* with a toothed cutting edge. Behind these is a pair of extra jaws, the *maxillae*. These are jointed and have a feeler or *palp* on each which touches and tests the ground as the animal walks along. Behind these again is a sort of jointed lower lip or *labium*. It is really another pair of extra jaws joined together.

INTERNAL ORGANS. When a cockroach is dissected by being opened down the back, it is seen that the various

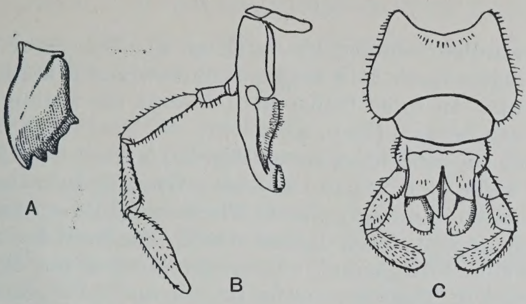

Fig. 58. *Mouth parts of cockroach.* The top of each mouth part in the figure is attached to the head. A, mandible; B, maxilla (with palp); C, labium.

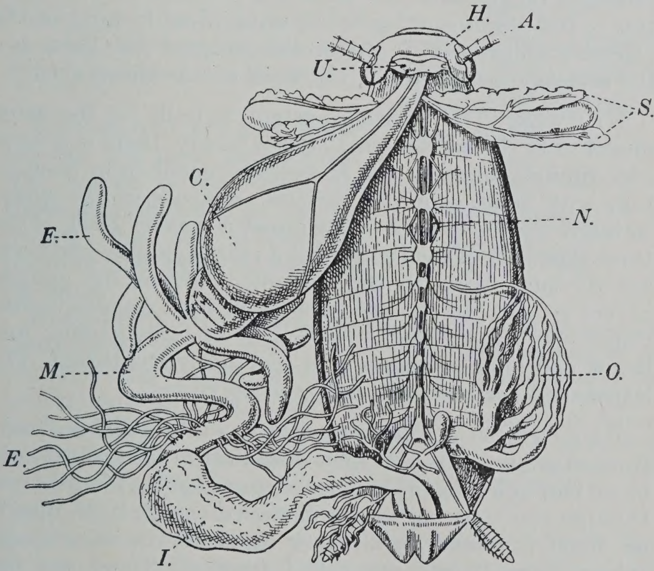

Fig. 59. *Dissection of female cockroach. A.* antenna; *C.* crop; *E.* excretory organs; *F.* finger-like glands; *H.* head; *I.* intestine; *M.* middle part of alimentary canal; *N.* nerve cord with ganglia; *O.* ovary; *S.* salivary gland; *U.* ganglion above the throat.

organs are surrounded by *fat* (Exp. 3). On top of everything is the *heart.* It is long and narrow and is made up of segments. In some transparent insects the action of the heart can be seen (Exp. 4).

When the *alimentary canal* (Fig. 59) is freed from fat it is found to be longer than the body. Opening into the front end is a pair of *salivary glands.* The saliva, like our own, has an enzyme in it which digests starch. The front bulky part of the alimentary canal is the *crop.* Most of the digestion goes on here. The enzymes for protein and fat digestion are made in finger-like glands behind the crop. Then comes the narrower *middle part* of the alimentary canal. Here the products of digestion are absorbed into the blood. After this is the *intestine* going to the *anus.* Just in front of the intestine are numerous thread-like outgrowths. These are the *excretory organs,* doing the work of our kidneys.

NERVES. The nervous system is built on the same model as in the earthworm. That is to say, there is a *nerve cord* running beneath the alimentary canal from head to tail, with *ganglia* in the various segments of the body. Actually the nerve cord of the insect is *double.* Each of the three segments of the thorax has a pair of ganglia and there are six such pairs in the abdomen. From the ganglia nerves go out. In the head the nerve cord divides to surround the throat, and it has a pair of large ganglia just below and another bigger pair just above the throat. The latter send nerves to the eyes and antennae.

BREATHING. Insects breathe in quite a different way from other animals. Oxygen does not go into solution in blood through lungs as in ourselves, or at gills as in fishes, or through the body surface as in the earthworm. In insects air itself is conveyed all over the body in microscopic tubes. These tubes are called *tracheae.* There are ten openings of the tracheae on either side of the body, two being in the thorax and eight in the abdomen. The holes lead into air tubes which branch many times and lead to every part of the body (Fig. 60). In this way oxygen is brought to the tissues, and carbon dioxide goes out by the same route.

The walls of the tracheae, which are made of *chitin*, are strengthened by a *spiral thickening*, like the wire in certain garden hose-pipes. The inner ends of tracheae actually go inside cells of the body. Under the microscope tracheae appear glistening white owing to the air inside them (Exp. 5). It is obvious that the cockroach has no need for haemoglobin, and indeed its blood is colourless.

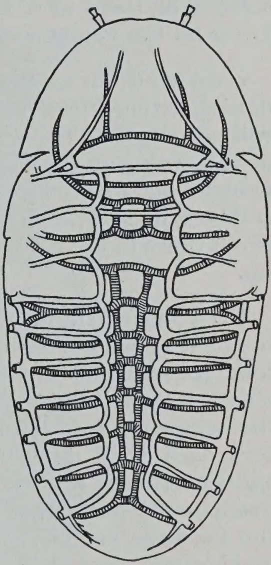

Fig. 60. *Tracheae of cockroach.* Some of the openings of the tracheae are seen along the sides of the body. Only the larger tracheae are shown: there are very many finer branches going to every part of the insect's body.

REPRODUCTION. Cockroaches are male and female. The *ovaries* in the female are tubes on either side of the abdomen (Fig. 59). These join together and open underneath the anus.

In *Hydra* (p. 113) the spermatozoa swam in the water surrounding the animal and then penetrated the eggs and so fertilized them. In the case of the sea urchin unfertilized eggs were laid by females in the sea water and then fertilized by spermatozoa swimming in the water around them. But in insects *fertilization* of the eggs takes place inside the body of the female. In all land animals it is necessary for the male to unite with the female to introduce spermatozoa, because the latter would die in the air if the eggs came out of the body to be fertilized. The liquid in which the spermatozoa swim would dry up.

After the eggs of the cockroach have been fertilized, sixteen of them at a time are laid in a horny egg case. Later on the young cockroaches hatch out.

GROWTH. Since the young insect is surrounded by its hard skeleton, growth offers a special difficulty. The skeleton will not expand. The way the difficulty is got over is this: at intervals the skeleton splits and the young cockroach wriggles out with its soft covering. The animal now swells[1] and then its skeleton hardens again. This *moulting* happens seven times in the twelve months the animal takes to grow up.

COMPARISON WITH EARTHWORM. It is clear that the plan of construction of cockroach and earthworm is in some respects the same. Both are segmented animals, with a nervous system of the same type. But in the earthworm the segments are all more or less alike, whereas in the cockroach they differ a lot from one another and the segmentation is not always very apparent. In the cockroach mouth parts, legs, ganglia, heart, and the openings of the tracheae are obviously segmental. But the insect is much more complicated than the worm. It has eyes, antennae, legs and wings. In other words, various parts of its body are specialized for particular jobs. This makes the segmentation of the body less obvious. The thorax, for example, has three segments, but the muscles that move legs and wings require a solid skeleton for attachment. So the thorax is made of one piece, not of three movable rings. The eyes and feelers of the head require large ganglia, and these in turn need protection, so the head too is in one piece, not jointed.

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[1] As Mr Weller would have said: "The insect is a-swellin' wisibly before my wery eyes".

## II. GRASSHOPPERS AND LOCUSTS

The *grasshopper* is nearly related to the cockroach. The most obvious difference is the large third pair of legs with which the grasshopper jumps. These insects, as everyone knows, make a chirping noise. The sound is produced not

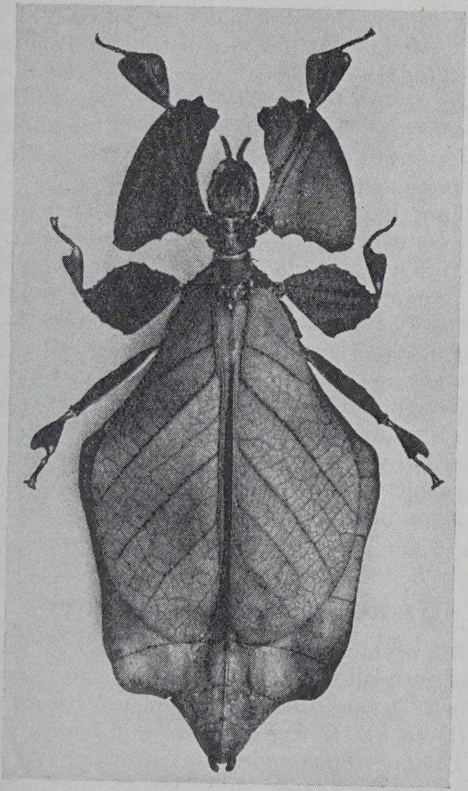

Fig. 61. *Leaf insect*. This insect closely resembles leaves in appearance and colour.

through the mouth but by the legs and wings. On the inner side of the largest joint of the hind legs there is a sort of file. The noise is made by rubbing these against the hard front pair of wings. The ears are on the first segment of the abdomen (Exp. 6). Only the males have a voice: females in this case are silent. The purpose of the sound is to attract the females, for they come towards a male that is chirping. An experiment has been made by putting a male and a female in separate rooms connected by a telephone. When the male started to chirp the female moved to the receiver of her telephone.

*Locusts* are like large grasshoppers. They are found in warmer countries than England and occasionally they move from place to place in vast swarms. They are voracious vegetarians. Soon after a swarm alights, crops over wide areas are stripped of all their leaves.

The *leaf insect* (Fig. 61) is not very distantly related to the cockroach and grasshopper. It lives in Ceylon. It is coloured green and has the appearance of a leaf and parts of leaves. Presumably the result of this is that the insect is not so easily seen by its enemies. Many animals are more or less invisible owing to coloration or shape, but few are such complete imitations of other objects as the leaf insect (Exp. 7).

## III. BUTTERFLIES AND MOTHS

Everyone who has kept silkworms at school knows that moths and butterflies start life in quite a different way from cockroaches. A worm-like *caterpillar* or *larva* comes out of the egg (Exp. 8). It feeds greedily on leaves and grows rapidly. Then it stops moving and growing, and surrounds itself by a protective case of silk. Within this silken case the caterpillar sheds its skin and becomes motionless. It is now known as the *chrysalis* or *pupa*. On the surface of the pupa can be seen the enclosed legs and wings of the moth into which the chrysalis finally changes by a further splitting of the skin. The *adult* stage has now been reached, and soon sexual reproduction takes place. Male unites with female to introduce spermatozoa. Then the female lays fertilized eggs.

*Moths* differ from *butterflies* in having hairy instead of smooth antennae (Exp. 9). Most moths have thicker bodies and duller colouring than butterflies, and they usually fly by night instead of in the daytime. When not flying moths generally hold their wings horizontally and butterflies vertically.

THE CABBAGE BUTTERFLY. This is one of the commonest butterflies. The *larva* or caterpillar is very destructive to cabbages (Fig. 62, A). Two *broods* of eggs are laid each year, one in May, the other in July or August. Clusters of these eggs can be found on the lower side of cabbage or nasturtium leaves (Exp. 10). In about seven to ten days the caterpillars hatch out of the eggs and begin eating the leaves. Just as in the case of the cockroach the chitin skin is *moulted* from time to time. When fully grown the caterpillar is 1½ inches long and yellowish green with stripes along it (Exp. 11). There are hairs on little bumps on the skin. The body is made of a *head* and *thirteen segments*, of which the first three form the thorax. On each segment of the thorax is a pair of jointed *legs* with a hook on the end. On some of the segments of the abdomen are so-called pro-legs. They have little hooks on them with which the caterpillar clings very firmly.

The caterpillar feeds hungrily, and for this purpose has a pair of strong jaws or *mandibles* which cut the leaves. On the lower lip or *labium* is a central *tube* through which a silk thread can be spun.

PUPA. When it has grown to full size, the caterpillar stops feeding and climbs upwards on any surface it can find. In climbing a *silk ladder* is formed out of the tube on the lip and is stuck to the surface by a side-to-side movement of the head (Exp. 12). Hanging on to this ladder with its pro-legs, the larva gradually works its way upwards. Then it stops and turns into the *pupa* (Fig. 62, B). The beginnings of wings, legs, antennae and large eyes now appear inside the hard chitin skin of the pupa. It remains quite still, only the abdomen moving from side to side if touched. The pupal stage lasts about two or three weeks if the larva came from the first brood of the year and pupated in June. If from the second brood, the pupa remains as such through the winter. Then in July and August, or in April and May as the case may be, the butterfly emerges by the skin of the pupa splitting.

ADULT. The adult insect (Fig. 62, C, and Exp. 13) has three pairs of *legs* and two pairs of *wings* on the thorax. The wings are strengthened by so-called "*veins*" of chitin. The pattern on the wings is a little different in the two sexes.

FOOD. Adult butterflies and moths feed on nectar (p. 159) from flowers. That is to say, they take in water and sugar only. This is sufficient as a source of energy for flight and for laying eggs, but without protein in the food no fresh protoplasm could be made. The adult, however, does not require this, for after it emerges from the pupa no more growth takes place. The larva has done all the growing, and for this purpose has eaten a full diet of leaves, containing both carbohydrates and proteins. In the pupa stage the tissues of the larva have been rearranged to form those of the adult. To allow of this, food reserves were stored up by the larva. But the adult requires an energy food alone, so sugar is enough for it.

To suit their special way of feeding, the *mouth parts* of butterflies and moths are different from those of the cockroach. They are for sucking juices, not for biting, yet some of the same parts are there. But in the adult butterfly the mandibles, so prominent in the larva, have gone. The pair of *maxillae* together form a long sucking tube (Exp. 14),

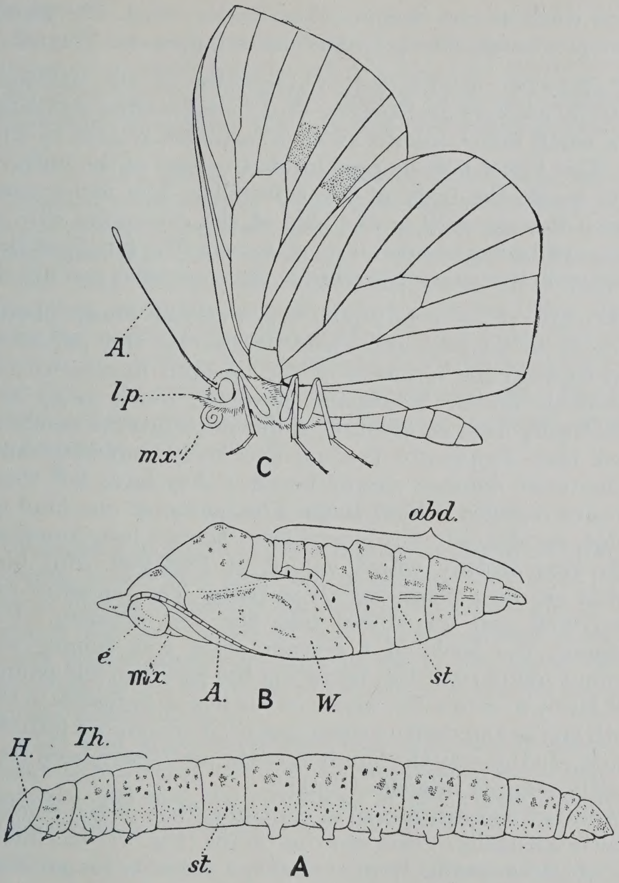
A.
l.p.
mx.
C
abd.
e.
mx.
A.
B
W.
st.
H.
Th.
st.
A

Fig. 62. *Life-history of the cabbage butterfly.* A, larva; B, pupa; C, adult. The three are enlarged to different extents. *A.* antenna; *abd.* abdomen; *e.* eye; *H.* head; *l.p.* palp of labium; *mx.* maxillae; *st.* opening of trachea; *Th.* thorax; *W.* wing.

which when at rest is coiled beneath the head. The small lower jaw or *labium* has two feelers or palps on it (Fig. 62).

PARASITE ENEMIES. Caterpillars of the cabbage butterfly are very destructive. But they are often attacked by a small insect known as an *ichneumon*, related to the bee. This insect lays its eggs inside the eggs of the butterfly or inside the body of the caterpillar. The ichneumon pierces the egg shell or the skin of the caterpillar with a sharp egg-laying needle on its abdomen. The larvae of the ichneumon live as parasites inside the caterpillar and kill it.

BIOLOGICAL CONTROL OF PESTS. Many plants valuable to man are destroyed by insects. But parasites help to keep the numbers of the harmful insects within reasonable limits. Nowadays, however, insect pests are often transported accidentally from one country to another. Then they frequently become extremely numerous and do immense damage simply because they have left their parasite enemies behind them. The larvae of one kind of midge, accidentally introduced from Europe into America, each year destroy wheat valued at £800,000. But biologists are now mastering these pests. The parasites are discovered and introduced into the new country. For instance, the larva of a certain moth was ruining the coconut industry of Fiji by eating the leaves of the palms. But lately a certain fly, whose larvae live as parasites in the moth larvae and destroy them, has been introduced into the island. In this way the numbers of the moth have been very greatly reduced in a short time.

Another successful case of control is that of the prickly pear in Australia. Years ago this cactus (Fig. 27) was introduced into Australia from abroad as a curiosity for gardens. The plant ran wild, and since the climate suited it and its enemies were left behind, it flourished and spread over vast areas. The prickly pear grows to a massive spiny plant and great tracts of country were made impossible for cultivation by its spread. A few years ago it already covered

60,000,000 acres and was gaining ground at the rate of 1,000,000 acres a year. But lately a certain moth has been imported specially from South America into Australia. The larvae of this moth eat the prickly pear, and, thanks to their rapid spreading, the cactus is now losing ground.

THE BALANCE OF NATURE. Both these cases of biological control show what man can do to keep down pests by supplying their missing enemies. But they show more than this. All animals and plants have their enemies. These may be animals which eat them, they may be parasites, or merely an unfavourable climate. But all the time the numbers of each kind of plant and animal are being kept down. If there are no enemies the balance is upset. In this way, for example, rabbits introduced into Australia have now become a plague, for there are no stoats, weasels or ferrets to kill them off.

## IV. FLIES AND MOSQUITOES

Flies and mosquitoes both belong to the same group of insects. When they come out of the egg they start life as *larvae* just as butterflies and moths do. This is the growth period. The larva sheds its skin (moults) several times. It turns into a *pupa*, the stage in which the organs of the larva are turned into those of the adult. From the pupa the winged *adult* emerges.

Flies and mosquitoes have only one pair of wings. In flight these wings move at an enormous rate. There are between 300 and 400 vibrations of the wings per second. This causes the buzzing sound.

THE FLY. Flies lay their eggs on excrement (faeces) or on putrifying animal or vegetable matter. Horse manure is a favourite site. The *larvae*, or *maggots* as they are called, burrow down into these materials and feed on them. The larva is white. It has a segmented body (Fig. 63 and Exp. 15). The *head* is at the pointed end. There are no eyes or limbs. Black *hooks* can be seen at the head end. These are used to help the wriggling movements of the body in getting the larva along, and also to tear up the food, which is only swallowed in a fluid state. At the broad hind end you can see two openings into the breathing tubes or *tracheae*. Fly larvae crawl directly away from a light (Exp. 16).

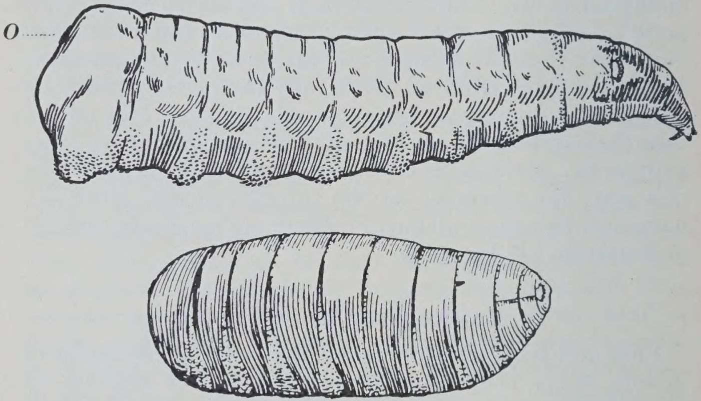

Fig. 63. *Larva and pupa of fly*. The larva is above (× 9), the pupa below (× 8). The head of the larva is on the right, with hooks projecting. *O* is one of the openings into the tracheae.

When the larva is fully grown it leaves the filth in which it has lived and crawls to a dry, and if possible a dark, place. Then its skin turns brown and hard. It has now changed into a motionless *pupa*. From this the *adult* fly will later on come out.

Everyone knows what a fly looks like (Fig. 64 and Exp. 17). It has two very large *eyes* on the head, and short *antennae*. Seen under a lens the eyes look like those of a cockroach or a butterfly. On the tip of each jointed leg is a pair of *hooks* on either side of a *pad* (Exp. 18). There is a sticky stuff on the pads which allows a fly to walk on a window pane. The hooks and pad help it in walking on the ceiling.

The *mouth parts* are constructed for sucking liquids. Under the microscope (Exp. 19) you will see that the mouth parts end in two cushion-like lobes. On these are numerous grooves or channels held open by incomplete rings of chitin. These channels run into main gutters leading to the mouth. The fly can only suck up liquid food. When it is eating sugar it first spits out a liquid to dissolve the sugar. The house-fly never bites, but it has a relation which is a blood sucker. This *biting fly* can pierce the skin and make a meal of blood.

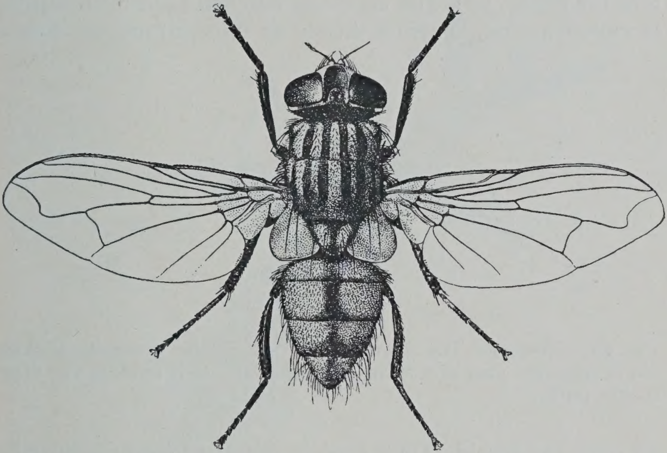

Fig. 64. *The fly*. Six times natural size.

Flies *breed* in the warmer months, and the rate of breeding is very great. A female can lay up to 150 eggs at a time, and she will do this half-a-dozen times in her short life. The rate of growth of the larva depends, of course, on temperature, but the pupa stage can be reached in four or five days. In warm weather the fly emerges about four days later. A fortnight after this the first eggs are laid. With this quick life and numerous eggs you can easily calculate how rapidly flies can spread if the temperature is right and food for the larvae is there.

THE MOSQUITO. Mosquitoes and gnats are very near relations (Fig. 65). The common English kind of mosquito is called a *gnat*. Various kinds of mosquitoes are found all over the world. They are abundant in warm countries, and they are almost incredibly numerous in northern Siberia.

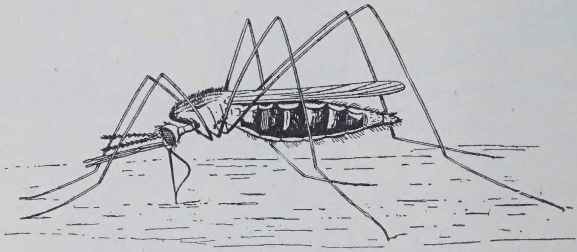

Fig. 65. *Mosquito*. The drawing shows a female mosquito sucking blood from the arm of a man. The bent labium is holding the other mouth parts.

Mosquitoes lay their eggs in water. The eggs float at the surface, and the larvae and pupae live in water. It may be a pond, a slow-running stream or a water butt. The *larva* (Fig. 66 and Exp. 20) has a hairy body, obviously divided into *head*, *thorax* and *abdomen*. The three segments of the broad thorax are fixed together. On the head are *eyes* and *antennae*. In front is a pair of bunches of hairs, something like shaving brushes. The rapid movement of these *brushes* sweeps the food of the larva into its mouth. The *food* consists of microscopic green plants like *Chlamydomonas*, floating in the water.

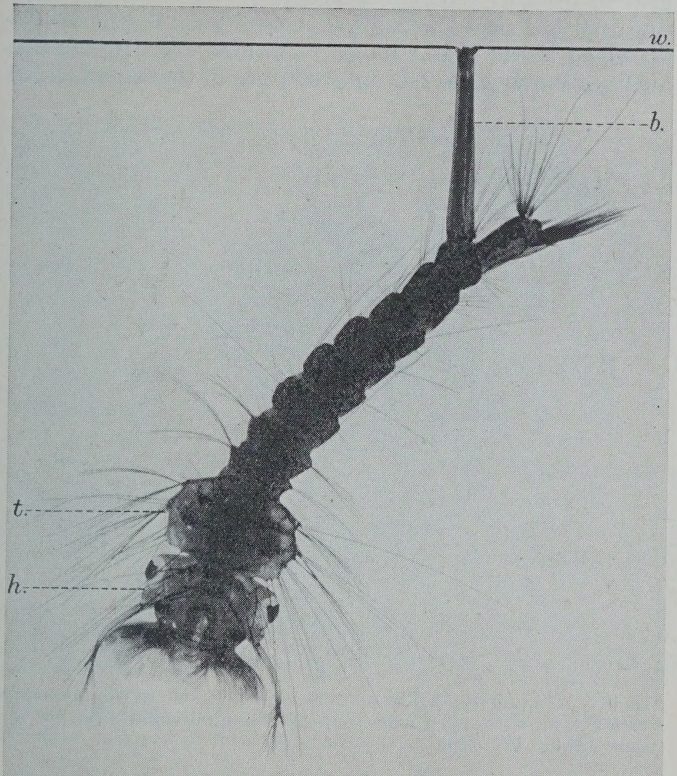

Fig. 66. *Mosquito larva.* Photograph of a living larva hanging from the water surface (*w.*); *b.* breathing tube; *h.* head with eyes, antennae and brushes; *t.* thorax. (J. F. Marshall.)

The last segment but one of the abdomen has a long outgrowth from it. This is for *breathing*. Although the mosquito larva lives in water, yet it does not take in oxygen dissolved in the water like a fish or *Hydra*. It breathes air from the surface. The outgrowth from the abdomen has two openings at its end which lead into the *tracheae*. There are no other openings into the latter. Mosquito larvae hang by their breathing tubes from the surface film of the water. While a larva is hanging in this position the brushes on the head are hard at work catching food. When the larva is disturbed it immediately closes the breathing openings by hinged flaps and vigorously wriggles down into the depths.

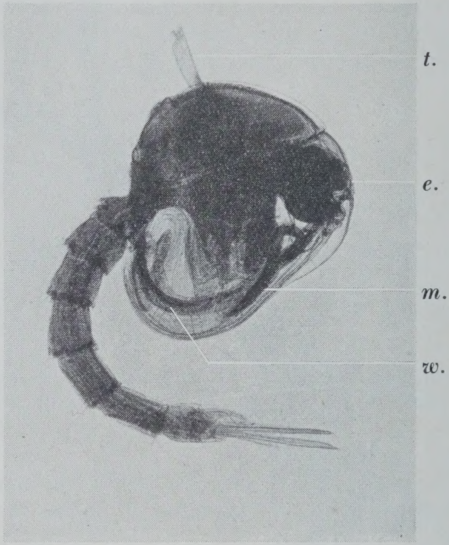

Fig. 67. *Mosquito pupa*. The photograph shows one of the breathing tubes (*t.*), an eye (*e.*), a wing (*w.*) and the mouth parts (*m.*) of the future adult.

After several weeks the larvae become fully grown and turn into *pupae*. These have quite a different shape (Fig. 67). The head and thorax are bulky and the beginnings of the wings, limbs and mouth parts of the future adult can be seen through the skin. The pupa breathes through two tubes on the thorax, by which it hangs to the surface film of the water. Unlike the motionless pupae of butterflies or of flies, the mosquito pupa can swim very actively by flapping its abdomen. But it does not feed.

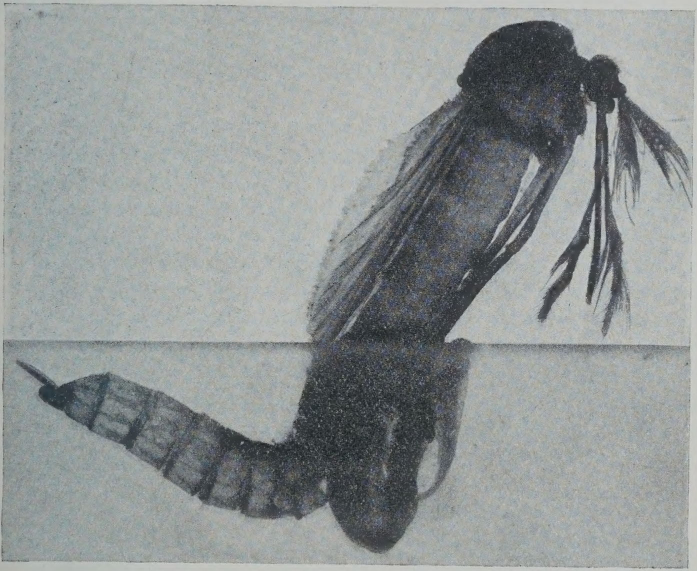

Fig. 68. *Mosquito coming out of pupa skin at the surface of the water.* This is an enlarged photograph of the living insect. (J. F. Marshall.)

The *adult* comes out of the pupa skin on the surface of the water, using the skin as a raft until its wings have hardened enough to fly off (Fig. 68). This takes five to ten minutes.

The chief interest of the mosquito to the man in the street—or in the field—is that it, or rather she, pierces the skin and *sucks blood*. For, as Kipling says, "The female of the species is more deadly than the male". The female alone is a parasite on animals; the male contents himself with plant juices. The male can easily be distinguished from the female because he alone has *feathery antennae* (Exp. 21). These hairs are probably his ears. With their help he can find the female by her buzzing.

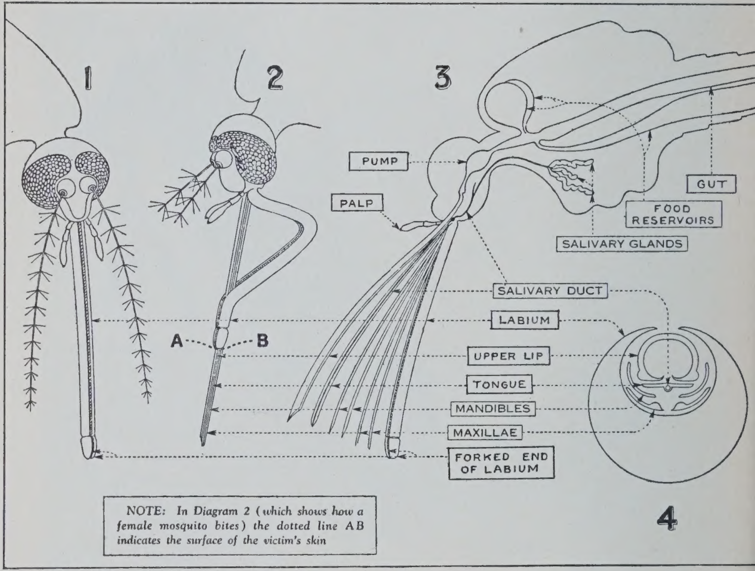
1
2
3
4
PUMP
PALP
GUT
FOOD RESERVOIRS
SALIVARY GLANDS
SALIVARY DUCT
LABIUM
UPPER LIP
TONGUE
MANDIBLES
MAXILLAE
FORKED END OF LABIUM
A
B
NOTE: In Diagram 2 (which shows how a female mosquito bites) the dotted line AB indicates the surface of the victim's skin

Fig. 69. *Mouth parts of a female mosquito.* 1, front view; 2, side view as the insect is "biting"; 3, section of thorax and head with mouth parts separated; 4, section across mouth parts. (J. F. Marshall.)

For piercing the skin and sucking blood the mosquito has a formidable collection of weapons. These correspond with the various *mouth parts* of the cockroach, but they are quite different in shape, since they have different tasks to perform. Fig. 69 shows the mouth parts as they are in the animal, separated from one another, and in section. There is a grooved "*upper lip*" which (with a "tongue") forms a tube. The blood is sucked up this. There is a pair of *mandibles*, a pair of *maxillae*, and a single "*tongue*", all of them like needles. These are all held together in the hollow *labium*. Outside of this are the *palps* or feelers of the maxillae.

When a mosquito bites, all the weapons held in the labium are thrust into the skin. The labium itself does not enter the skin but guides the other mouth parts, holding them between its forked end as a billiard player supports his cue. The labium is flexible, and when the other mouth parts have gone right in it is bent double (Figs. 65 and 69). The tongue has a minute tube in it, the *salivary duct*, and through this tube liquid from the insect's salivary glands is squirted into the wound. This liquid prevents the blood from clotting, as this would spoil the feast. Incidentally the saliva stings us. Then the blood is pumped up the tube formed by "upper lip" and "tongue" into the insect's alimentary canal.

## V. DISEASE CARRIERS

You know that many human diseases are due to parasitic bacteria. Others are caused by protozoa, that is to say one-celled microscopic animals related to *Amoeba*. The bacteria are blown about in the air as spores. They may infect a man in this way, or by reaching his body in food or water. But bacteria are also carried by insects, and many protozoa which cause diseases, for example malaria, are carried from man to man in this way.

HOUSE-FLY. This is one of the worst offenders. It settles on all kinds of filth and picks up dirt containing bacteria on the hairs of its legs. A fly may alight on human faeces containing *typhoid* bacteria and later on deposit these on our food or milk. Flies transport the germs of *tuberculosis* from spittle on which they alight. They are responsible for much *eye disease* among natives of tropical countries, and they carry *cholera* germs. It is clear then

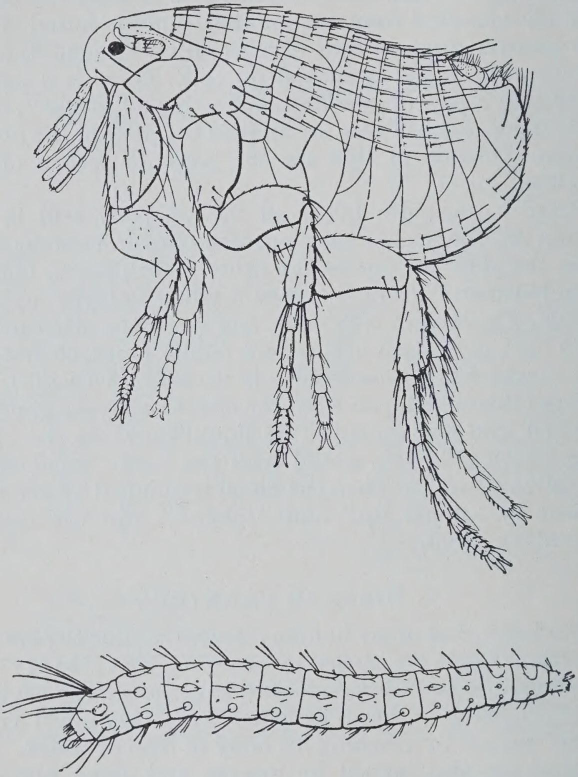

Fig. 70. *Flea.* The upper figure shows the flea; the lower figure is its larva. The upper figure was drawn by Robert Hooke in 1665.

that it is of the greatest importance to keep down the numbers of flies. This cannot be done by killing the adults, for a few uncaught females can lay large numbers of eggs. The breeding places must as far as possible be made impossible for the flies. Garbage and dung must not be left near human dwellings. It should be covered up, burnt or treated with disinfectants.

THE FLEA. Fig. 70 shows you what a flea looks like. It has no wings, but has long powerful legs for leaping (Exp. 22). Its body is compressed from side to side. The flea passes through larval and pupal stages. The larva lives in cracks in the floor and other such places.

Different species of animals have each their own kinds of fleas. Monkeys, by the way, have none. It is a rat flea which is so dangerous to man, for it carries the germs of *plague*, the Black Death of the fourteenth century. Plague is a disease both of the rat and of man. The flea may suck the blood of an infected rat. The plague bacteria multiply in the gut of the flea. If by chance this flea then attacks a man, owing to the mass of bacteria in its gut it cannot suck in all the blood it wants. Some of the blood flows back out of the flea into the puncture with bacteria in it and so it infects the man.

Fleas cannot be exterminated, although their numbers can be reduced by keeping houses clean, but you see how very important it is to keep down the numbers of rats.

THE LOUSE. The louse is another wingless insect, but very different in appearance from the flea (Fig. 71). It is responsible for spreading *typhus fever*. When it sucks blood, at the same time it deposits its faeces containing the germs on the skin of its victim. The person bitten naturally scratches the irritating spot, and this rubs in the germs. The eggs of the louse are attached to human hairs.

THE MOSQUITO. This insect is responsible for spreading *malaria*. The malaria germ is a protozoan. It is sucked into the insect's alimentary canal with the blood when a fever patient is stung. It passes through the gut wall into the body cavity of the mosquito, multiplies enormously there, and then goes into the insect's salivary glands

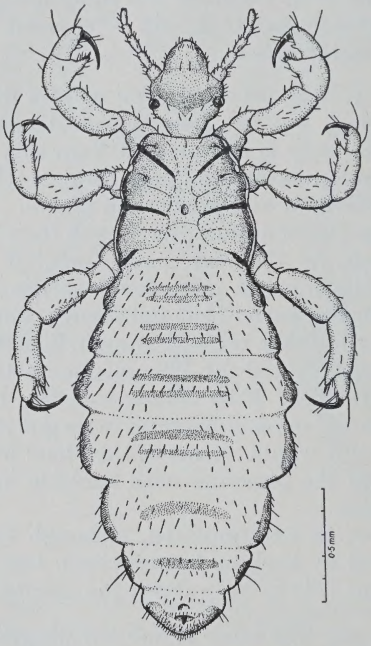

Fig. 71. *Louse.* (D. Keilin.)

(Fig. 69). When now the mosquito stings another man, the insect's saliva, as you know, is squirted into the wound through the canal in the "tongue", and so the malaria parasites enter.

Great efforts are made to reduce the numbers of mosquitoes in many countries where there is malaria. This is done by pouring oil on to the water containing the larvae.

With oil on the surface the larvae cannot use their breathing tubes and they die. *Yellow fever* is a tropical disease which is also carried by mosquitoes. It was only after mosquitoes which carry this disease had been killed off in Panama that the canal could be built.

## VI. SOCIAL INSECTS

Bees, wasps and ants are called social insects because they live together in communities. The offspring do not leave their parents, but work together to bring up further generations.

THE BEE. The *hive* is an aid given by man to the bee. It is just a more convenient place for the bee to make its nest in than the hollow of a tree. Nearly all the inhabitants (Fig. 72) are *workers*. These are really *sterile females*, that is females which never produce eggs. In the hive is one single *fertile female*, the *queen*. In addition, there are *males* called *drones*. The workers do all the duties in the colony except reproduction.

When bees hatch out of the egg they start life as white legless *larvae* or *grubs* (Fig. 73 and Exp. 23). Then they turn into *pupae* in which beginnings of legs, wings, eyes and mouth parts can be seen. From the pupae *adults* emerge, queen, workers or drones. Note that bees have four wings, not two like flies. A queen may live five years, but workers die after eight weeks. Three weeks are spent before coming out of the pupa.

Inside the hive is the *comb*. It consists of innumerable six-sided *cells* made of *wax*, with passages between. Some cells have an egg laid by the queen in each of them. The larvae hatching from these eggs turn into pupae. Other cells are stores of food, either honey or pollen.

DUTIES OF THE WORKERS. Men have different callings or professions, but a worker bee does all the different jobs in the hive in regular order one after another as she grows older. On coming out of her pupa skin she first rests and then she cleans out the cells from which others have just emerged. Unless the cells are cleaned the queen will not lay another egg in each. Next the worker feeds the helpless grubs in their cells with honey and pollen from the stores. Her following job is to take nectar (p. 159) from the mouths of older workers returning from visiting flowers. She sucks the nectar into her own mouth. Inside her

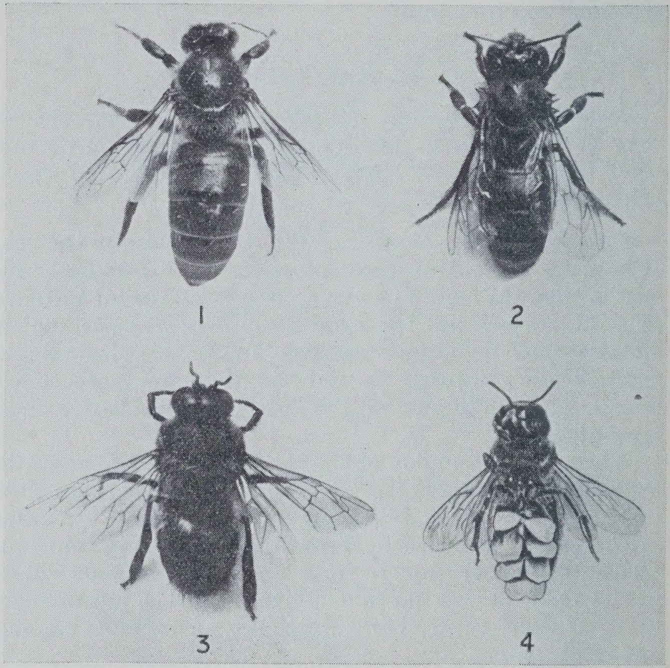

Fig. 72. *Bees.* 1, queen; 2, worker; 3, drone (notice large eyes); 4, worker with wax coming out of glands.

gut it is changed chemically and she squirts it out again as *honey* into the storage cells. And she packs *pollen* (p. 158) brought home by other older workers into pollen cells. She is also a dustman, carrying dirt outside the hive. Then she takes to building new cells with wax coming from glands on her abdomen (Fig. 72).

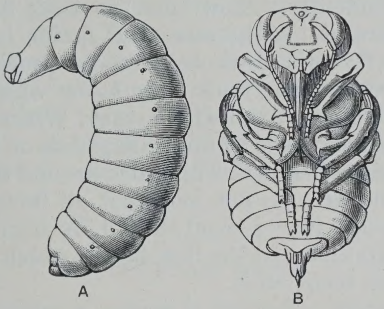

Fig. 73. *Larva and pupa of bee.* A, larva viewed from the side: the openings of the tracheae are seen on the sides of the segments; B, pupa viewed from underneath: antennae, mouth parts and legs of the future adult bee can be seen.

During this period the worker flies out occasionally. Each flight is longer than the last, until she gets to know all landmarks in the neighbourhood. In her fifth week of life the worker serves for a short time as a doorkeeper. She smells the entering bees with her antennae and drives off all strangers to the hive, bees or others, stinging them if necessary with the sting at the end of her abdomen. Then finally she begins to gather food, nectar or pollen, from the flowers. The pollen is packed into sticky balls on the hairs of her hind limbs.

THE LANGUAGE OF BEES. Bees are attracted to flowers by their colours and their scents, but the way in which a bee, when she has found a flower with a good supply of nectar, informs her fellow workers is most remarkable. On her return home she has a language to tell the news. But it is not speech. It is a language of *dance* and *scent*. She executes a dance in the hive, running in circles, and this excites other workers to go out and bring in the nectar. The discoverer then returns to her find. The others get there too, but they do not follow her as a guide. They get there independently. How then do they find the right flowers? They do so because the finder brought back traces of the flower's scent on her body. During the dance the others smelt this. Thus they know which flowers to visit. But this is not the whole story. When the bee first made her discovery, she let out from glands on her abdomen a special scent of her own. This stuck around the flower. So the fresh gatherers go out and visit all flowers they find having the same flower scent, but if by chance they find it they go especially to the first flower which has the discoverer's own scent on it.

SWARMING. When the hive is getting overcrowded the workers raise a few larvae to become *new queens*. Large cells are built for these and the old queen lays eggs in the special cells. When the larvae emerge from these eggs they are given food with more pollen than usual in it, that is, food richer in protein. This turns the female grub into a fertile queen, instead of into a sterile worker. Just before the new queens emerge from their pupae, the old queen flies out of the hive with half its workers. This is a *swarm*. They go off to found a new colony. If the bee-keeper is quick enough he gets them to enter one of his empty hives.

Then a new queen emerges in the hive. Soon she flies out followed by the drones. This is her *nuptial flight*. One of the males unites with her, and leaves in her body a store of *spermatozoa* which will serve for the rest of her life. After this, queen and drones return to the hive and the workers in the hive kill the other queen pupae. The colony thus starts off afresh with a new queen. In the autumn the drones are all turned out of the hive and they die either of starvation or they are stung to death by the workers.

ANT SOCIETIES. The social system of ants is in many ways more elaborate than that of bees. They keep *domestic animals*, they are *agriculturalists*, and some kinds make *slaves*. Their cattle are plant lice, relations of the green fly found on rose bushes. These insects produce a sugary liquid which ants like, and the ants tickle them to get it. The agricultural ants bring pieces of leaves into their nests and manure them with their own faeces so that fungi grow on the leaves. The ants enjoy eating these fungi. The slave-makers capture the workers of other kinds of ants to work for them.

## PRACTICAL WORK

*Exp.* 1. Examine a cockroach externally, using a lens.

*Exp.* 2. The separated mouth parts should be shown to the class.

*Exp.* 3. Dissection of a female cockroach.

*Exp.* 4. Watch the heart beating in a living larva of *Chironomus* or *Corethra,* held in a compressorium or under a cover-slip supported at the corners by wax, and examined under a low power of the microscope.

*Exp.* 5. Examine tracheae under the microscope. They can be seen very clearly through the transparent body wall of a living blow-fly larva held in a compressorium and examined with a low power objective (one-inch).

*Exp.* 6. Examine a grasshopper. Look with a lens for the sound-producing organs and for the ear drums.

*Exp.* 7. When in the country look out for resemblances of insects, birds, etc., to their surroundings.

*Exp.* 8. Rear silkworms.

*Exp.* 9. Compare a moth with a butterfly.

*Exp.* 10. Watch a cabbage butterfly visiting cabbages and search for the eggs. Mark a leaf with eggs on it and visit it daily, noting the behaviour of larvae, and dates of hatching, moults and pupation.

*Exp.* 11. Examine a large caterpillar with a lens. Make out the structure of the body and watch the movements of the jaws in feeding.

*Exp.* 12. Keep fully fed caterpillars with leaves in a wide glass candle-screen cylinder covered with muslin. Watch climbing on glass, formation of silk ladder and pupation. Later on look for emergence of adult.

*Exp.* 13. Examine the structure of a butterfly.

*Exp.* 14. Watch butterflies feeding on a drop of sugar solution.

*Exp.* 15. Examine living larvae of house-flies or blow-flies. These can be purchased at a fishing bait shop. Notice the mode of locomotion. Examine with a lens. After a time the larvae will pupate. The pupae should be examined.

*Exp.* 16. Fly larvae crawl directly away from a light.

*Exp.* 17. Examine a fly with a lens.

*Exp.* 18. Look at the foot of a fly under the microscope.

*Exp.* 19. Study a fly's mouth parts under the microscope.

*Exp.* 20 Catch gnat larvae and pupae and study their behaviour and structure.

*Exp.* 21. Examine male and female gnats under a lens.

*Exp.* 22. Study a flea under the microscope.

*Exp.* 23. Examine with a lens larva, pupa and adult bee. Look for pollen combs and baskets. If possible visit a hive and talk to bee-keepers.

## CHAPTER XI

# FLOWERS

We have spoken of higher plants and lower plants. These are also called *flowering* plants and *flowerless* plants, for only the higher plants have flowers. Mosses and ferns have none, nor have pond scums and moulds. Flowers bear the reproductive organs of the higher plants. They produce the seeds which grow into the next generation of plants.

### I. THE BUTTERCUP

STRUCTURE OF THE FLOWER. Each flower is borne on a *flower stalk*. To the top of this the various parts of the flower are attached (Exp. 1). On the outside are five green *sepals*, looking rather like ordinary leaves (Fig. 74). They protect the flower bud before it opens. Inside the

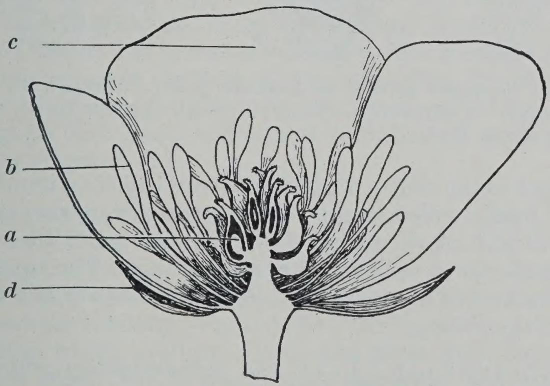

Fig. 74. *Buttercup flower* cut down the middle. The carpels are in the centre at the end of the flower stalk. One of them (*a*) clearly shows the ovule inside the ovary. Then come stamens (*b*), petals (*c*) and sepals (*d*).

sepals are five yellow leaves, the *petals*. (In the *lesser celandine* the sepals are yellow like the petals.) Each petal is above and between two sepals.

Inside the petals come a large number of yellow *stamens*. Stamens again are a special kind of leaf, although they do not look at all like leaves. A stamen has a thin stalk and a swollen end called the *anther* (Fig. 75 and Exp. 2).

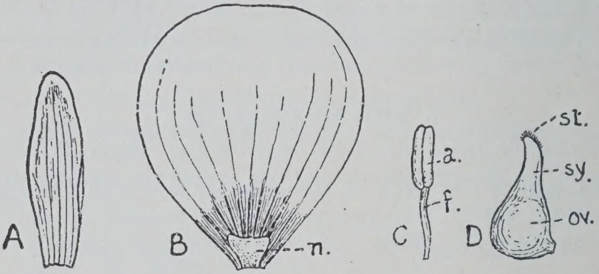

Fig. 75. *Separated parts of the buttercup flower.* A, sepal. B, petal; *n.* nectary. C, stamen; *a.* anther; *f.* stalk. D, carpel; *ov.* ovary; *st.* stigma; *sy.* style.

Right in the centre of the flower you will see a number of green bodies called *carpels*. These again are another special kind of leaf. A carpel has a swollen lower part, the *ovary*,[1] and a narrower upper part called the *style*. The tip of the style is known as the *stigma*. Within the ovary is a round body, the *ovule*.

POLLINATION. Inside the anthers *pollen grains* are produced (Exp. 3). When the anthers are ripe their walls burst and the pollen is set free. When the ovules are ripe the stigmas become sticky.

The next thing that happens is that pollen grains get on to the ripe stigmas. Pollination is the name given to the transfer of pollen from the burst anthers on to the stigmas. As soon as the pollen grains get on to the stigmas a thin tube, the *pollen tube*, grows out of each pollen grain (Exp. 4). This pollen tube grows down from the stigma through the style towards the ovule. One of the pollen tubes, that one which has grown out quickest, penetrates into the ovule. A nucleus in the pollen tube then fuses with the nucleus of a cell inside the ovule. Later on each ovule develops into a *seed*, while sepals, petals and stamens wither away.

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[1] The ovary of a flower does not correspond to the ovary of an animal (p. 39).

Pollination in the buttercup and many other flowers is done by insects. The whole reason for the *scents* and *colours* of flowers which we admire so much is not to please us, but to attract insects to transfer pollen from anthers to stigmas. Butterflies, bees and other insects visit coloured flowers, not with the disinterested idea of transferring pollen from anthers to stigmas, but to get food (p. 153). The buttercup and many other flowers provide a sugary liquid for insects, called *nectar*. The *nectaries* which produce it can be seen in the buttercup at the base of each petal (Fig. 75). While the insects are engaged in their own food collecting, pollen clings to their hairy bodies and is rubbed off again on the sticky stigmas.

ALTERNATION OF GENERATIONS. Such is the process of reproduction in flowering plants. Liverworts, mosses and ferns, you will remember, have an alternation of a sexual with an asexual generation. The moss plant reproduces sexually. From its fertilized egg cells sporogonia develop which produce spores and these grow into moss plants again. The liverwort does the same. The fern prothallus reproduces sexually, and its fertilized egg cells grow into fern plants which bear spores to give more prothalli. At first sight it looks as if there were nothing like this alternation of generations in flowering plants. Pollination and its results look like quite another story. Nevertheless there is an alternation of sexual with asexual stages in all flowering plants.

Table A. *Corresponding stages in the life-histories of various plants.*

| | Moss and liverwort | Fern | Flowering plant | |
|---|---|---|---|---|
| Asexual generation | Sporogonium | Plant | Plant | |
| Leaves bearing sporangia | — | Frond | Stamen | Carpel |
| Sporangia | Spore-forming cells in capsule | Sporangium | Anther | Ovule |
| Spores | Spore | Spore | Pollen grain | Spore inside ovule |
| Sexual generation | Plant | Prothallus | Male prothallus: in pollen grain | Female prothallus: in ovule |
| Gametes | Spermatozoid and egg cell | Spermatozoid and egg cell | Nucleus in pollen tube | Egg cell |

The familiar flowering plant, the buttercup for instance, is the *asexual stage*. It corresponds to the fern plant and it produces *spores*. Instead of the *sporangia* being on all the leaves as in the fern, they are on special leaves in the flowers. These special leaves bearing sporangia are the stamens and the carpels. Moreover, instead of there being one kind of spore as in the fern or moss, there are two kinds, the *pollen* and the *spore which is inside the ovule*. But where is the sexual stage into which the spores develop?

The truth is that the *sexual stage* in the life of the flowering plant is both shortened and very much reduced in size.[1] The spores produce a sexual stage, but instead of this being a visible plant like the liverwort, moss or prothallus, it is microscopic.

Moreover, the story is made more complicated by another circumstance. In the liverworts, mosses and ferns the spore developed into a sexual plant which bore both male and female organs. In other words, the liverwort and moss plants, and the fern prothallus, have both male and female organs like *Hydra* or the earthworm. But in the flowering plants, as you saw, there are *two different kinds of spore*. One kind, the pollen, develops into the *male sexual stage* in the life history. The other kind of spore, one inside each ovule, develops into the *female sexual stage*.

Pollen grains (spores) grow pollen tubes. Inside each pollen grain the male sexual stage is formed, and there is a single nucleus in the pollen tube which is the *male gamete*. This corresponds to a spermatozoid. The female stage arises from the spore which is inside the ovule. In it is an *egg cell*, the female gamete. *Fertilization* occurs when the male gamete from the pollen tube unites with the nucleus of the egg cell. Table A may make this complicated story clearer.

You will learn later (p. 184) what is the advantage to the plant of this telescoping of the sexual stage, and of the existence of two kinds of spores giving rise to separate male and female stages.

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[1] In the fern, too, the sexual stage (prothallus) is reduced and shortened compared with the sexual stage of the moss or liverwort.

## II. THE PEA

SYMMETRY. All the petals of a buttercup are alike. This is not so in the pea flower (Fig. 76). Here the petals are of three different shapes. The buttercup is star-shaped.

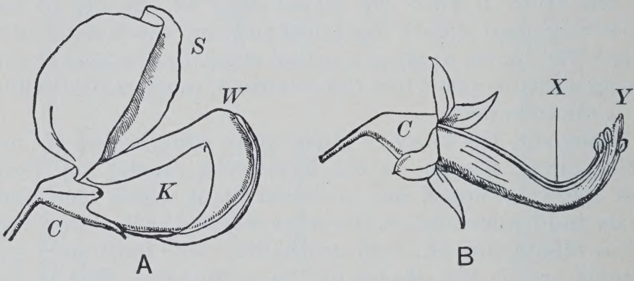

Fig. 76. *Flower of sweet pea.* A shows the whole flower. *C*, sepals; *K*, keel; *S*, standard; *W*, wings. B shows the nine united stamens enclosing the ovary, and one free stamen (*X*) forming a lid to the trough. The style (*Y*) can be seen sticking out between the anthers.

It is said to have *radial symmetry*, like a wheel. The pea, on the other hand, is *bilaterally symmetrical*. A plane through the middle cuts the flower into two halves, one of which is the mirror image of the other. Among animals, *Hydra* is radially symmetrical, while the earthworm, insects and we ourselves have bilateral symmetry. It is true that one side of our body is not the exact mirror image of the other. The heart is rather to one side and nobody has both sides of the face identical. The earthworm, however, is exactly the same on both sides. The reason why the pea flower has its particular shape is to help insects to bring about pollination.

Clover, lupin, laburnum and bean plants belong to the same family and have similar flowers.

STRUCTURE OF THE FLOWER. There are five *sepals* which are joined together forming a kind of cup (Fig. 76 and Exp. 5). The petals, too, are five in number, but they are not all alike. They are of three kinds. These are (i) one *standard* at the top of the flower, (ii) two *wing* petals at the sides, and (iii) two petals below, joined along their edges to form the *keel*.

The ten *stamens* and single *carpel* are hidden inside the keel. Nine of the stamens are joined together, forming a *trough*. Only the ends of these stamens with the *anthers* are free. The tenth stamen is not joined to the others but forms a *lid* to the trough. Inside the trough is the *nectary*.

The single *carpel* is hidden in the trough of stamens. The *ovary* is nearly transparent and you can see a number of *ovules* inside it. The *style* (or pistil) is the bent end part of the carpel, sticking up between the anthers. On the top of the style is the *stigma*. After fertilization of the egg cells inside the ovules, the ovary develops into the *pod*.

CROSS-POLLINATION BY INSECTS. In most plants it is not good for egg cells to be fertilized by male gametes which have arisen from the same flower. The seeds which result grow into weakly plants. To avoid this, various means are taken to transfer the pollen from one flower on to stigmas in another flower. This is cross-pollination. The design of the pea flower is largely for this object. In cases when stigmas do receive pollen from the same flower they are said to be self-pollinated.

Flowers of the pea family are cross-pollinated chiefly by bees. The insect, attracted by the scent and colour of the flower, alights on the wing petals. There is a nectary hidden inside the trough of the stamens. The bee pushes her mouth parts between lid and trough of stamens to get nectar which she carries away to her hive to make honey.

The weight of the bee's body forces down wing petals and keel. But the stiff tube of stamens, with the style inside it, now sticks out. The weight of the bee's body causes the style to move forwards like a piston between the anthers. As a result, a ring of hairs on the style sweeps the pollen out on to the underneath side of the bee's abdomen.

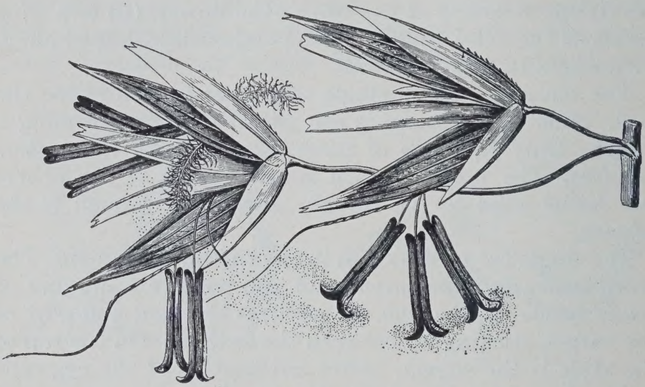

Fig. 77. *Grass flowers* with hanging anthers and feathery stigmas. Pollen is being blown from the right-hand flower on to the stigmas of the left-hand flower.

But the stigma at the end of the style, being further out than the ring of hairs, touches the bee first. In this way any pollen from another flower, which the insect may have sticking to its body, gets first on to the stigma. After this has happened, pollen swept out by the hairs on the pistil gets on to the bee's body. This pollen will stick to the stigma of the next flower the bee visits.

You can imitate the bee's actions by pressing down on the wing petals of a pea flower with your finger (Exp. 6). The style will push out pollen.

WIND POLLINATION. Not all flowers are brightly coloured. Some are green. These do not depend on insects for pollination, but the pollen, which is particularly light, is blown by the wind from flower to flower. *Grass* is a good example (Fig. 77). The anthers can easily be seen hanging out of the flower. The stigma is very hairy, thus catching flying pollen easily (Exp. 7).

### III. THE DEAD-NETTLE

The dead-nettle flower has five *sepals* joined into a bell, and five *petals* also joined together forming the peculiarly shaped flower seen in Fig. 78. The *stamens* are four in number. Between the *anthers* can be seen the two-lobed *stigma.*

CROSS-POLLINATION is done by bees. Nectar is produced by a *nectary* at the bottom of the tube of petals. The bee alights on the lower lip of the petals and pokes her head down to get the nectar. In doing so her whole body blocks up the entrance of the flower. Since the front lobe of the stigma projects further out than the anthers, it touches the bee's back first and receives pollen which she has brought from another flower. Then pollen from the anthers is rubbed on to the body of the bee. When the bee visits the next flower, this pollen will first touch its stigma (Exp. 8).

If you dissect the flower you will see a ring of *hairs* at its inner end. They protect the nectary from small insects. If these could get at the nectar they would crawl all over the parts of the flower and transfer pollen from anthers to stigma, causing self-pollination. Small holes are often seen at the lower end of the tube of petals. These holes have been made by little insects which have stolen nectar.

Mint, sage and lavender belong to the same family as the dead-nettle.

### IV. THE SUNFLOWER

The "flower" of the sunflower, daisy or dandelion is not a single flower but a *group of flowers* packed close together to form a *head* (Fig. 79). Each of the flowers in the centre of the head of sunflower or daisy has five petals joined together

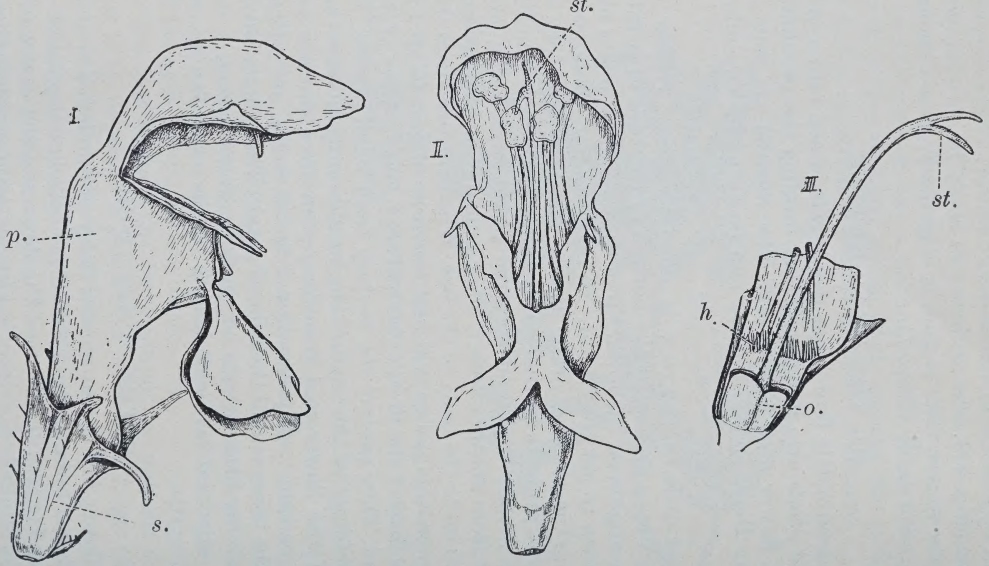

Fig. 78. *Flower of dead-nettle.* I shows the sepals (*s.*), and the petals (*p.*) with a landing stage for bees. In II the front lobe of the stigma (*st.*) is seen projecting out beyond the four anthers. III shows the ovary (*o.*), style and stigma (*st.*), and the hairs (*h.*) which protect the nectar.

(Exp. 9). Around the edge of the head of the sunflower the flowers also have five petals joined together, but three of these petals are much longer than the others. In the dandelion all the flowers have their five petals joined together, and they grow out to one side to make a sort of tongue (Fig. 80). In the dandelion the sepals are hair-like.

Each of the central flowers has five *stamens*. The stems of the stamens are free from one another, but the *anthers* are joined together. They form a tube surrounding the *style*.

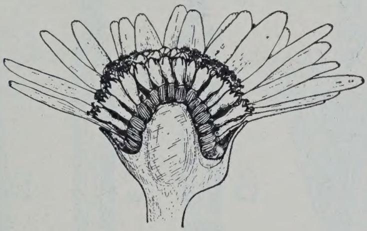

Fig. 79. *Flower head of a daisy*, cut in two. The central flowers have short petals, those at the edge have three united petals drawn out into tongues.

The arrangements for *pollination* are very curious. The anthers ripen before the stigma. In each flower on the head the pollen is first shed inwards into the tube between the anthers. Then the pollen is pushed out of this tube by the lengthening of the style (Fig. 80, B). In this process pollen does not reach the stigma, because the end of the style is split and the two surfaces of the stigma facing one another are pressed close together. Small insects crawling about on the head in search of nectar pick up the pollen that has been pushed out in the way just described. Later on the stigma becomes ripe. Its two surfaces are now separate from one another (Fig. 80, C). They are ready to receive pollen brought by insects from another flower.

But if no insects happen to cross-pollinate the stigma, the flower is not beaten. The two ends of the stigma then curve downwards and pick up pollen from the same flower on to their sticky surface (Fig. 80, D). Self-pollination results.

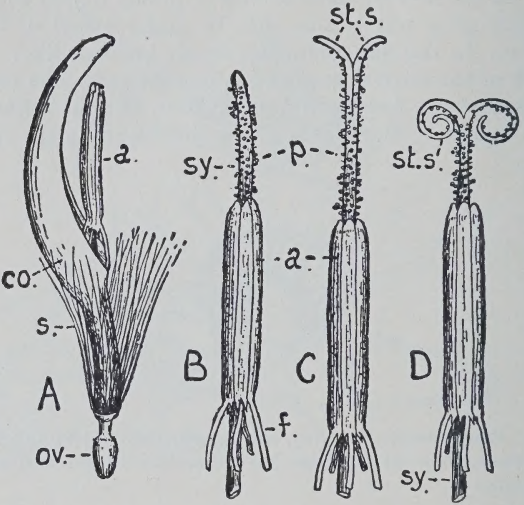

Fig. 80. *Dandelion.* A, young flower. B–D, stages in pollination. *a.* anther; *co.* petals; *f.* stalk of stamen; *ov.* ovary; *p.* pollen; *s.* sepals; *st.s.* surfaces of stigma; *sy.* style.

## V. THE SNAPDRAGON

This is another flower with bilateral symmetry (p. 162). There are five sepals and there are five petals which are joined together to form a tube, the mouth of which is almost closed (Exp. 10). Nectar is produced at the bottom of the tube. Pollination is done by bees. A bee forces her way into the mouth of the tube of petals, completely blocking up the entrance with her body. Consequently the four anthers and the stigma rub against the bee's back. This may result in either self- or cross-pollination.

To ensure cross-pollination the *figwort,* another plant of the same family as the snapdragon, has a stigma which ripens before the anthers. Many flowers have the reverse arrangement: the anthers ripen before the stigma. This is the case, for example, of the common *cowparsnip*, which belongs to the same family as the carrot.

## VI. THE PRIMROSE

This flower has a very ingenious arrangement for cross-pollination, and quite a different one from anything we have yet met. There are two distinct types of flower which are borne on separate plants. These are called *pin-eyed* and *thrum-eyed* (Exp. 11). In the former, the stigma can be seen at the entrance of the tube formed by the five united petals. In the thrum-eyed flowers the anthers are at the opening. Fig. 81 explains the structure of the two kinds of flowers. In one the stigma is above the anthers: in the other it is the reverse.

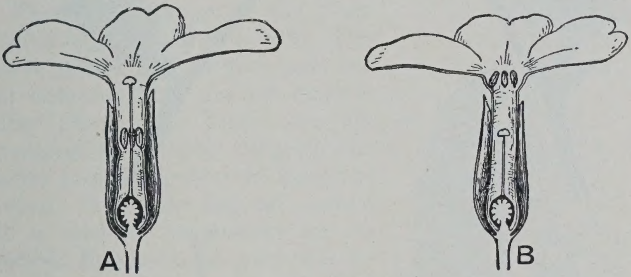

Fig. 81. *Primrose:* pin-eyed (A) and thrum-eyed (B) flowers cut down the middle.

Bees visit the flowers. In the pin-eyed type the pollen, which is sticky, becomes attached to the bee's head. When a bee visits a thrum-eyed flower, this pollen will stick to the stigma, which is just at the right level. If a bee first visits a thrum-eyed flower you can work out for yourself what will be the course of events. The "primrose by the river's brim" is not so simple after all. It should be added that although primroses possess this device for cross-pollination, the flowers are often self-pollinated.

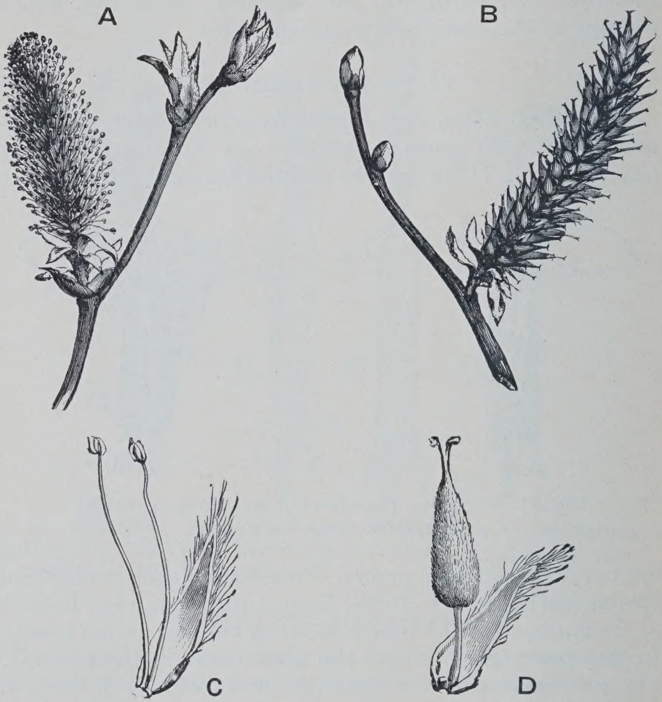

Fig. 82. *Willow*. A, catkin of flowers bearing stamens; B, catkin of flowers bearing carpels; C, flower with stamens; D, flower with carpels. Each flower has a scale-like leaf to protect it.

## VII. THE WILLOW

This is a tree which has flowers grouped together in *catkins*. Its special interest is that there are two sorts of catkins (Fig. 82 and Exp. 12). These are borne on separate trees. One kind of catkin has flowers with *stamens but no carpels*. The stamens give it a yellow colour. The other has *carpels only* and is olive-green. Neither kind of flower has any sepals or petals. Cross-pollination is of course the only possible method of pollen transfer. It is carried out by bees and other insects.

### VIII. THE TULIP

The tulip belongs to the same family as lilies and hyacinths. The three petals and three sepals are all coloured and are all exactly alike (Exp. 13). There are six stamens and three carpels, the latter joined together to form the ovary. The tulip has no nectar. It is visited by insects for its *pollen*. For bees, as you will remember (p. 153), not only take nectar from flowers but they also carry away pollen to their hives for food. The tulip gives them pollen alone and so incidentally gets cross-pollinated.

### IX. THE PINE

Pine *cones* correspond to flowers (Fig. 83). The tree has two separate kinds of "flowers" (Exp. 14). One of these produces pollen, the other bears ovules. Neither kind has sepals or petals, but merely scale leaves which correspond to the stamens and to the carpels of the flowers we have studied already. Pollination is done in May and June by the

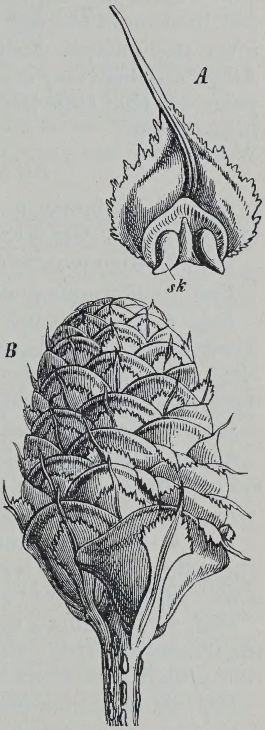

Fig. 83. *Female cone of the silver fir*. A, scale separated to show the two ovules (*sk*) on it. B, young cone.

wind. Pollen from one kind of "flower" falls on to the two ovules borne on each scale of the other kind of "flower". The ovules are exposed, not enclosed in an ovary. But fertilization of the egg cells does not take place until a year after pollination. Meanwhile the green cone is growing. After fertilization, seeds are not formed for yet another year. By that time the cones have changed into the familiar brown form.

### PRACTICAL WORK

*Exp.* 1. Examine a buttercup flower and cut it through longitudinally. Use a lens to examine it.

*Exp.* 2. Remove stamens and carpels for study under a lens.

*Exp.* 3. Examine pollen grains under a microscope.

*Exp.* 4. Shake pollen grains from a wild hyacinth or other flower into a beaker containing a 10 per cent. solution of sugar. Next day pipette out the pollen and examine it under the microscope to see pollen tubes.

*Exp.* 5. Examine the pea flower and then dissect its parts.

*Exp.* 6. Gently depress the wings and keel of a pea flower and see how the pollination mechanism works.

*Exp.* 7. Examine a grass flower with a lens.

*Exp.* 8. Study the pollination mechanism of the dead-nettle. The yellow archangel is a near relation of the dead-nettle and is a very suitable flower to study.

*Exp.* 9. Examine a sunflower or dandelion and then dissect the flowers and study them with a lens. Look for flowers with ripe anthers and others with ripe stigmas.

*Exp.* 10. Examine the snapdragon.

*Exp.* 11. Look for pin-eyed and thrum-eyed primroses. Cut the flowers open and study the arrangement of anthers and stigmas.

*Exp.* 12. Examine the two types of willow catkins with a lens.

*Exp.* 13. Examine the tulip.

*Exp.* 14. Look at branches of a pine tree in May or June to see (i) pollen-producing "flowers", (ii) cones of first, second and third years' development.

## *CHAPTER XII*

# FRUITS AND SEEDS

After the egg cell inside the ovule of a flower has been fertilized, the *ovule* grows and develops into the *seed*. This contains a young or *embryo* plant. Later on the seed will fall to the ground and *germinate*, developing into a new plant.

The fruit. When the seed begins to form, there is no more use for the sepals, petals and stamens of the flower. They wither away. But the *ovaries* have not finished their work. They grow bigger and become the *fruit* surrounding the seed.

In popular language a fruit is something juicy that we can eat. But to the botanist the word "fruit" means more than this. For many flowers form hard fruits. Plums, apricots, currants, melons and oranges are fleshy, edible fruits. But the nuts of the hazel and beech are equally fruits, formed by the growth of the ovary. And so too are the pods of peas and beans, and the small dry fruits of the buttercup.

The seed. Inside the fruit are the seeds formed from the ovules of the flower. Examples of seeds are peas, melon seeds, orange pips and date stones. But in the plum things are more deceptive. Here, both the edible portion and the stone are parts of the fruit, formed from the ovary, while the kernel inside the stone is the seed.

Spreading of seeds. There are two reasons why fruits are formed. One is to protect the seeds while they are developing. The other is to spread them from place to place. This is the only chance that plants have of travelling.

Plants produce enormous numbers of seeds, but very few of these ever grow into new plants. For they are spread in all directions more or less haphazard, and few of them will chance on the right kind of soil. Buttercups will not grow well in a wood nor the lesser celandine in dry places. Moreover, when numerous seeds do fall on suitable ground and all germinate, only a few survive. Only the strongest seedling plants will be able to grow, ousting their neighbours in the struggle for food and room. Thus it is necessary for plants to produce great numbers of seeds so that they may be spread in all directions and a few healthy plants grow up in the right places.

Since seeds cannot travel under their own power, they must be transported in various ways. Some seeds are shot out from the plants which produced them by a sort of explosion. Others are carried by the wind, by water and by animals.

EXPLOSIVE FRUITS. When the fruit is a dry one, its walls may split and shoot out the seeds, while the fruit is still attached to the plant. In the *gorse*, *broom* and *vetch*, for example, which are plants of the pea family, the pods dry and curl, forcing out the seeds some feet away (Fig. 84, A, B). You can hear the crackling of these fruits on a fine day.

The *violet* has an ovary made by three carpels. When the fruit is ripe, these three separate from one another into boat-shaped parts (Fig. 84, C). Then the sides of each boat in drying press on the seeds and shoot them out, like cherry stones shot from the fingers.

SPREADING BY WIND. The wind spreads very many different kinds of seeds and fruits from place to place. Fruits and seeds are constructed in various ways to take advantage of the wind.

Some seeds are very small and light. *Orchid* seeds, for example, can be blown long distances by the wind. Some dry fruits are on stiff long stalks and the seeds remain in them until shaken out by the wind. The *poppy* (Fig. 84, D) fruit, for instance, has a ring of small openings at the top, like a pepper box. The seeds are shaken out through these holes when the stalk is bent by the wind and rights itself again. The seeds are then blown away a certain distance. Grains of *corn*, too, are blown about by the wind. After the army had advanced into Palestine in the War, enormous areas of uncultivated land were seen on which barley was growing from grains blown away from forage dumps.

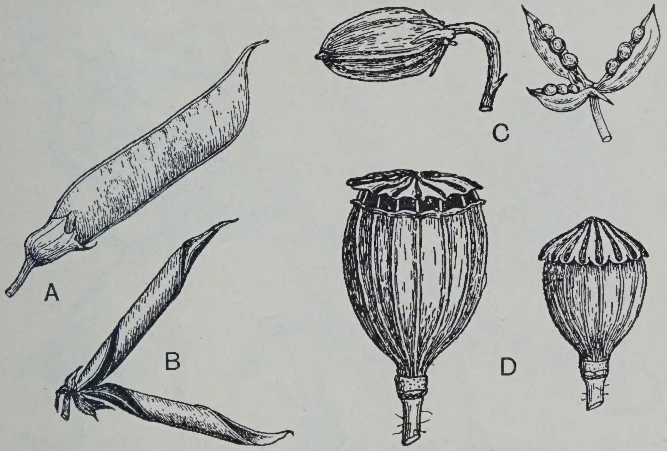

Fig. 84. *Fruits*. A, pod of vetch; B, same, after seeds have been expelled; C, violet fruit shut and open; D, old and young poppy fruits.

But often *hairs* and *wings* are developed so that the wind may be more effective in transport. Sometimes these outgrowths are on the seeds themselves and the seeds are blown about after they have left the split fruits. This is the case with the hairy *poplar* and *willow* seeds. *Cotton* fibres are hairs on the seed of the cotton plant which serve the same purpose. In other cases it is the fruit which has a hairy parachute and so is blown away with the seeds inside it. In the *wild clematis* the styles turn into long feathery plumes (Fig. 85, B). In the *dandelion* the hair-like sepals (p. 167) turn into the parachute (Fig. 85, C–E). While still all together on the flower head these fruits form the well-known "one o'clock". Darwin pointed out how very successful is this method of spreading. A kind of thistle introduced from Spain to La Plata in South America gradually covered huge areas, crowding out other plants.

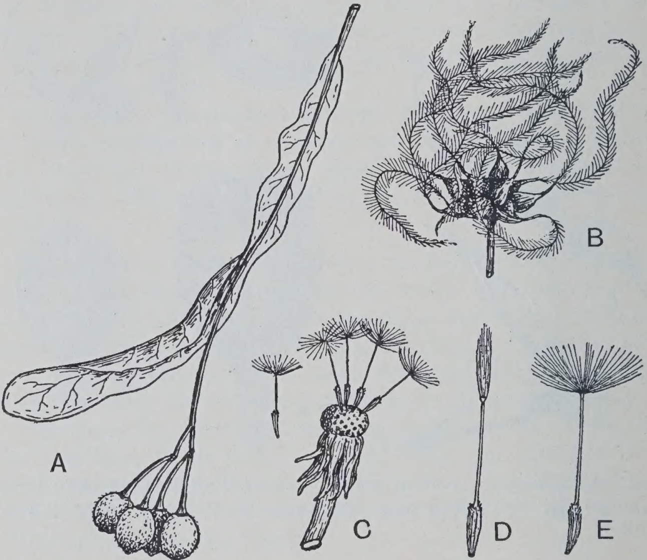

Fig. 85. *Fruits spread by the wind.* A, lime; B, clematis; C–E, dandelion.

Sometimes fruits or seeds have so-called *wings*. In the *lime* there is one wing on a stalk bearing several fruits (Fig. 85, A). The *elm*, *ash* and *sycamore* have wings on the fruits themselves (Fig. 86, A). Small light seeds and fruits which have hairs on them can be carried further by the wind than the heavier fruits with wings. The latter are all on trees, not on low-growing plants, and so the wind has a better chance of carrying them some distance.

Water transport. Plants which live in the water or beside water have fruits or seeds which float, and are transported by streams. Examples are the *water lily*, *rushes* and *sedges*. The coconut is the large fruit of the *coconut palm*. It floats and is often carried great distances by ocean currents. In this way the palm has been spread to islands throughout the South Seas.

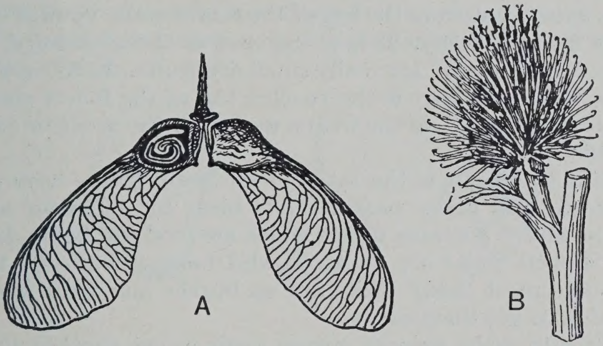

Fig. 86. *Fruits.* A, winged fruit of sycamore with ovary wall cut away on left to show coiled embryo. B, hooked fruits of burdock.

Spreading by animals. There are several different ways in which seeds may be transported by animals. In the first place, small fruits or seeds can stick to the animals' feet, embedded in mud. Birds are the chief agents in this kind of transport. Darwin removed the soil from the foot of an injured partridge and grew as many as eighty-two seedlings from it. Obviously no special structures are developed by the plants for this kind of spreading.

Then there are *dry hooked fruits* which cling to the coats of animals. The *burdock* is a common plant with these hooked fruits (Fig. 86, B). Such fruits are found on plants growing on the ground, where animals could brush against them.

FLESHY FRUITS are eaten by birds and the seeds pass out with the faeces of the animals. The fleshy part is digested but the seeds escape digestion because they are surrounded by a hard coat. The hard part may be formed by the coat of the seed itself, as in *grape* and *currant* seeds, or it may be the inner part of the fruit, as in *cherry* and *plum* stones.

Sometimes the fruit is formed, not in the usual way from the ovary, but from the top of the flower stalk, swollen out and become fleshy. This is the case of the *strawberry*, in which the "seeds" are really small dry fruits. In the *apple*, too, the edible part is the swollen top of the flower stalk, while the "core" is the ovary wall with the seeds or pips inside it.

But the result is the same in all fleshy fruits, however formed. The fleshy part attracts birds by its colour and taste, and it contains sugars which are food for them. Just as winged fruits are on trees, and hooked fruits on the ground, most fleshy fruits are on bushes and trees where birds can get them easily.

Finally, some animals spread seeds in yet another way. *Squirrels* make hoards of nuts, and *ants* store the seeds of gorse and other plants. All of the seeds are not eaten and some germinate later on.

## PRACTICAL WORK

Study the structure of the fruits and seeds mentioned in this chapter.

## *CHAPTER XIII*

# GERMINATION AND GROWTH

A SEED contains an embryo plant and it contains a store of food. When the seed germinates, the young plant grows and uses up this reserve of food until it is big enough to carry on photosynthesis with its first leaves and to absorb salts through its young roots. We shall study three different kinds of seeds.

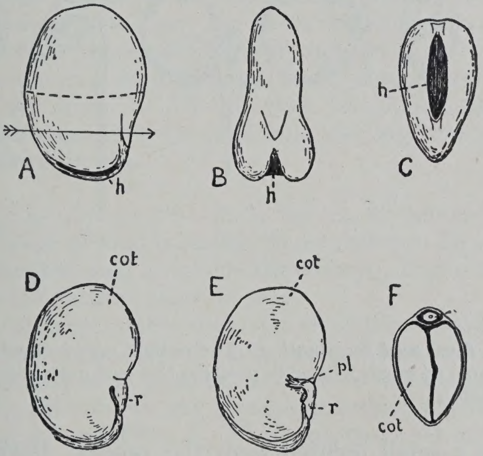

Fig. 87. *Bean seeds.* A–C seen from the outside; *h*, scar of stalk which attached seed to pod. D, embryo after removal of seed coat. E, embryo with one cotyledon removed. F, seed cut along arrow in A. *cot*, cotyledon; *pl*, plumule; *r*, radicle.

STRUCTURE OF THE BEAN SEED. Broad beans should be soaked in water for a day or so (Exp. 1). They absorb water, becoming larger and softer. A broad scar is seen at the thicker end of the seed (Fig. 87). This is the place where the seed was attached by a stalk to the pod. Covering the seed is a thin *seed coat* which can be removed. All that is inside this is the *embryo* plant. Most of it is made up of two thick leaves called *cotyledons*. They can be separated from one another. On one side of the embryo, at the place where the two cotyledons are joined together, there is a small pointed root, the *radicle*. Between the cotyledons is a small bud, the *plumule*, consisting of a very small stem and folded leaves.

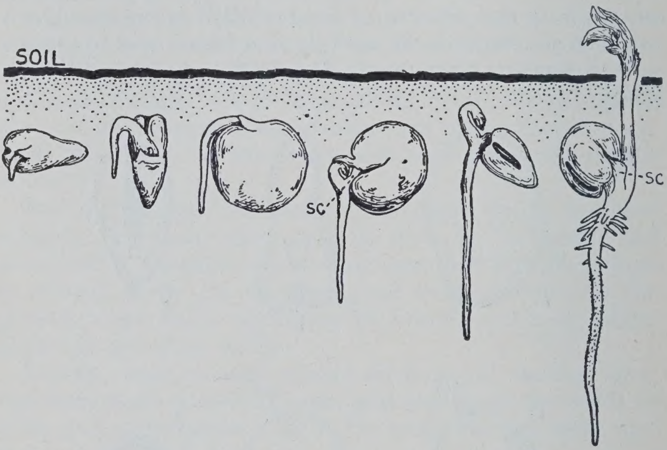

Fig. 88. *Bean seed germinating*. The radicle grows downwards and the plumule upwards whatever position the seed may be in. *sc*, stalk of cotyledon.

The cotyledons are thick and fill up most of the seed, because they contain a store of food in their cells. It is mostly starch (Exp. 2), but there is also a certain amount of protein.

Germination. Usually a period of rest is necessary after seeds are formed before they will sprout or germinate.

Most seeds wait through the winter and germinate in the spring. But many are able to wait years before they sprout. Bean seeds which had been kept in a museum 100 years have been known to germinate.

When the bean germinates (Exp. 3), first the seed coat splits and the radicle grows out. The young root grows downwards (Fig. 88) no matter in which direction the seed may be lying. Next the plumule grows out. Just as the radicle grew downwards, the plumule grows straight upwards. The plumule is at first bent double. The result of this is that the delicate young leaves are not injured while the plumule pushes its way up through the soil. When the young stem arrives above the earth it straightens out and its leaves turn green. Chlorophyll appears in them. Meanwhile the root has become longer and side roots have begun to grow out from it. All this time the young plant has been absorbing the stored food from the cotyledons, which slowly shrink in size.

CASTOR-OIL SEED. It is not in all kinds of seeds that the store of food is inside the cotyledons. In some the food within the seed is outside the embryo. This is the case, for instance, in the castor-oil seed.

When the seed coat is removed, the whitish food store is seen. It contains a lot of oil in place of the starch of the bean, and also some protein. If the food mass is cut in two vertically, the embryo can be seen embedded in the middle of it (Fig. 89 and Exp. 4). There are two thin cotyledons with a very small plumule between them and there is a radicle.

When the seed germinates (Exp. 5) the cotyledons first start absorbing into themselves the store of food which is all around them. Before long the seed coat is burst by the growth of the young plant. In the germinating bean the plumule elongated, but this is not the first thing that happens in the sprouting castor-oil seed. Here the region between the cotyledons and the radicle becomes longer.

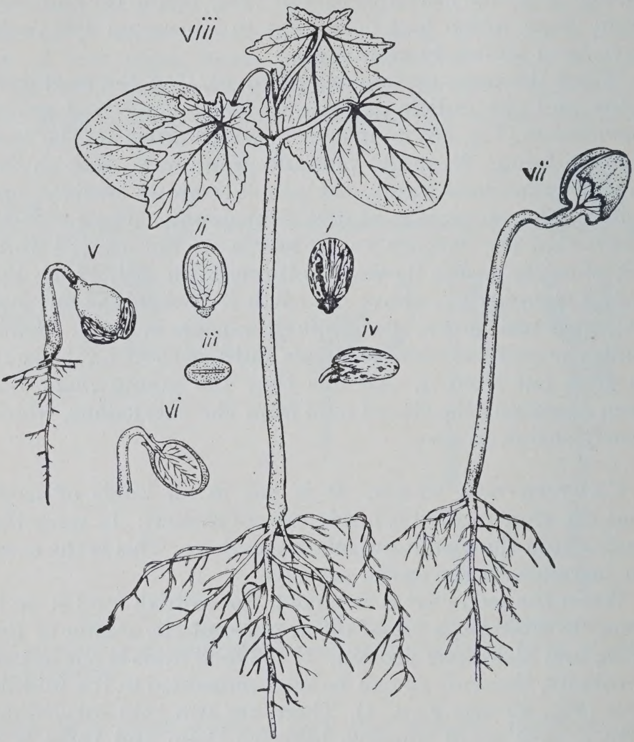

Fig. 89. *Castor-oil seed.* i, seed from outside; ii, seed cut in two to show one of the cotyledons; iii, seed cut across showing cotyledons surrounded by food; iv and v, seeds germinating with cotyledons still in food mass; vi, same cut in two; vii, cotyledons being raised above the ground, with food still attached to them; viii, young plant with oval cotyledons expanded and first ordinary leaves.

This raises the cotyledons above the ground while the radicle grows downwards and becomes a branching root. At first the stem bearing the cotyledons is bent double, with the same result as in the case of the bent plumule of the bean seedling.

Later on the stem straightens and the cotyledons turn green. Meanwhile, the remains of the seed coat, which the cotyledons have dragged up from the earth with them, falls off. At the same time the plumule is developing and the first pair of real leaves grow out above the cotyledons. It can be seen now that the cotyledons have a different and simpler shape than the later leaves. It is clear that the cotyledons first absorb the food from the seed into the embryo, and afterwards they carry on photosynthesis.

MAIZE. In the maize, wheat and other cereals we have yet another type of seed. Here again the food store of the seed is outside the embryo, but this time there is a single cotyledon and it is not leafy.

On one side of the maize grain is a whitish patch (Fig. 90). Underneath this lies the embryo. When the grain is cut in two through the middle (Exp. 6) the embryo can be seen. The rest of the seed is filled with reserve food, mostly starch. This food is gradually absorbed into the embryo through the cotyledon.

When the seed germinates (Exp. 7) the radicle appears first and grows downwards. The plumule then makes its appearance. It is enclosed in a sheath which protects the young leaves as the plumule pushes its way through the earth, growing straight upwards. Once in the air, the young green leaves come out of the sheath.

THE BENEFIT OF SEEDS TO THE PLANT. Seeds are formed from ovules. The ovules are within ovaries for protection, and the ovules receive food for the growth of the seeds from the plant which bears the flowers. When formed, the seeds each contain an embryo plant with a store of food to start it in life. And there are special arrangements for subsequently distributing the seeds far and wide.

Only the flowering plants have seeds. Mosses, liverworts and ferns have none. But it is the flowering plants which are the most successful land plants on the surface of the earth. Mosses, liverworts and ferns are found locally: flowering plants are everywhere. This is largely because they alone possess seeds.

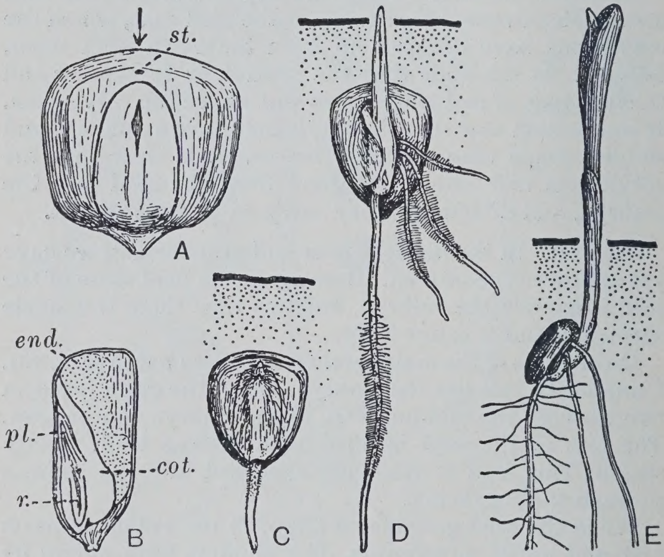

Fig. 90. *Maize grains.* A, whole grain; *st.* remains of stigma. B, grain cut down the middle; *cot.* cotyledon; *end.* reserve food; *pl.* plumule; *r.* radicle. C–E, stages in germination.

THE ADVANTAGE OF TWO KINDS OF SPORE AND OF THE SHORTENED SEXUAL GENERATION. You can now understand the advantage to flowering plants of having two kinds of spore (pollen and spore in ovule) giving rise to separate male and female sexual stages, and of the telescoping of these sexual stages (p. 161), for this modification of the life-history enables seeds to be formed.

Within the ovule is the female sexual stage, and in this there is an egg cell, or female gamete. The latter will develop into the embryo, while the ovule will turn into the seed containing the embryo. But before the egg cell can develop into an embryo it must first be fertilized by a male gamete. The male gamete is produced by the male sexual stage within the pollen grain (spore). The male gamete, however, could not swim to the egg cell in the way that the spermatozoid of a moss or fern does. There is no water for it to swim in, and the egg cell is hidden away within the ovule, itself inside the ovary. So the male gamete is transferred passively by the pollen tube to the egg cell. The pollen tube grows down through the style, and then the male gamete moves inside the pollen tube to bring about fertilization.

THE USES OF SEEDS BY MAN. Seeds, as you have seen, are packed with food materials. For this reason they are the most important crops grown for human consumption. The cereals, belonging to the grass family, are the most valuable. These are wheat, barley, rye, oats, maize and rice. They contain chiefly starch, but also quite a lot of protein. The latter varies in amount in different grains: wheat contains more than rice. The pea family supplies another very important group of seeds, including beans, peas and lentils. They have a higher proportion of protein to starch than the cereals. Then there are seeds containing oil, particularly those of palms, which are a very important food in Africa. Nowadays palm oil is extracted for making margarine. Linseed (from the flax plant) and cotton seed (from the cotton plant) supply oils for foods and for various industries. Oil from sunflower seeds is extensively used in Russia for cooking.

CONDITIONS FOR GERMINATION OF SEEDS. When seeds are planted, they do not sprout unless they are watered or unless it rains. Dry seeds do not germinate (Exp. 8). *Water*, then, is one of the necessary conditions for germination. You have seen from your experiments that when beans or other seeds are soaked they swell up. Water is absorbed into them before they start to germinate.

Seeds that fall on the ground from plants in the autumn do not sprout until the spring. This is partly because, as you know, a time interval is necessary before seeds will sprout, partly because a certain amount of *heat* is necessary. The higher the temperature, the quicker sprouting takes place. This is true up to a certain temperature. Above this plants are killed. The heat then upsets the normal chemical reactions in the protoplasm. Not only germinating seeds but all plants grow quicker and quicker as the temperature rises, up to a point above which they die.[1]

But some plants flourish at rather higher temperatures, others at lower. That is why there are different floras in arctic, temperate and tropical countries.

Germinating seeds *respire*, like all living organisms. They absorb *oxygen*. Consequently, seeds cannot germinate in places where oxygen is lacking. They will not sprout in waterlogged soil. Indeed, the respiration, and so the oxygen intake, of germinating seeds is particularly active, more so than in other parts of plants. You have seen a result of this already in the amount of *heat* which is produced by sprouting seeds (p. 3). The reason, of course, for this very active metabolism is that while the seed is germinating growth is very rapid. Much energy is required for the quick building up of fresh protoplasm and cells.

Water and oxygen, then, are necessary for germination to take place, and heat influences the rate at which seedlings grow. But there is another factor which affects the growth: this is *light*. You have probably seen that when a large stone or plank is lifted up in the garden, the grass underneath is long and it is yellow instead of being green. This is because plants grow more in darkness than in light, but in the dark they do not develop chlorophyll. An experiment with germinating seeds kept in the dark will prove this (Exp. 9). Of course, after a time the plants kept in darkness die. When the seedlings have used up all the food in the seeds they must die in the dark, since without chlorophyll and light they cannot carry on photosynthesis. But even in dim light plants grow more than in bright sunlight. In a wood the vegetation on the ground is higher than in a field. And this greater growth in dim light is of use to plants. For when they are crowded together, those that are shaded by the leaves of others grow quicker and so bring their leaves into the sunlight which they need.

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[1] This is true also of animals, except birds and mammals which have a controlled body temperature (p. 239).

ENZYMES. Most of the stored food in seeds is *starch* or *oil.* This is needed to supply energy to the young seedling plant as it grows. For this purpose the carbohydrate or the oil will be oxidized in respiration. The stored food is required, too, as building material. But the starch or oil must first be moved from its storage place in the seed (inside or outside the cotyledons according to the kind of seed) into the young root, stem and leaves. How is this removal done?

The starch is turned into *sugar.* Starch is insoluble, sugar is soluble in water, and therefore in the form of sugar the carbohydrate can move in solution to the place where it is wanted. You will remember that when *malt* is formed from barley for brewing, starch turns into sugar in this way (p. 79). The change from starch into sugar is done by an *enzyme.* There is an enzyme for this purpose in the seed, like the ptyalin which acts on starch in our mouth (p. 7). In other words, the starch in the seed is *digested* to sugar.

Seeds not only contain starch or oil but *proteins* in addition. These, too, must be moved into the growing seedling. So the stored proteins are broken down by enzymes into *amino-acids,* just as happens in our own alimentary canal. The amino-acids are soluble in water. They move in solution into the seedling and then are built up into other proteins to make the new protoplasm.

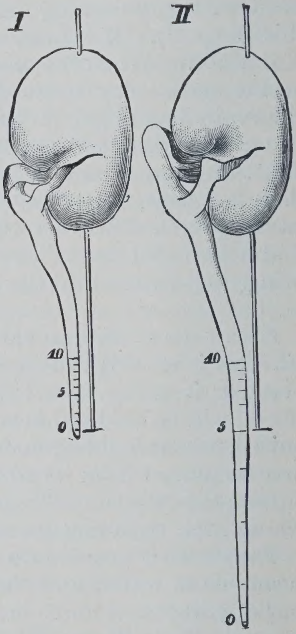


Fig. 91. *Germinating bean.* I, root tip marked with ink lines 1 millimetre apart; II, same root 24 hours later.

GROWTH. As a seedling elongates, certain parts of it grow fastest. This can be seen in a simple experiment (Exp. 10). If stripes of Indian ink are made at equal distances apart on the root of a bean seedling, then as it grows the marks become farther and farther apart. But it is soon seen that the greatest separation of the stripes is immediately behind the tip of the root (Fig. 91). This is true both of root and stem. The *growing region* is just behind the tip of each.

Plants are made of cells, and so as a plant grows the cells must become more and more numerous. This is, of course, what is going on in the growing regions. The *cells divide* and divide again. All the time new protoplasm is being formed and the cells are dividing. But after a while they divide no more. Yet the growth of the cells has not stopped yet.

Each cell continues to grow bigger up to a certain point. But now it grows, not by making more protoplasm, but by *swelling* itself up with *water*.

Water is taken into the cells by osmosis (p. 43). The water collects in a *vacuole* of *cell sap* (p. 95) in the middle of each cell (Fig. 92). At the same time the cell wall is enlarging. So you see that not only protoplasm and the cellulose of cell walls, but water too is one of the building materials of plants. This must be added to the uses of water to the plant given on p. 67.

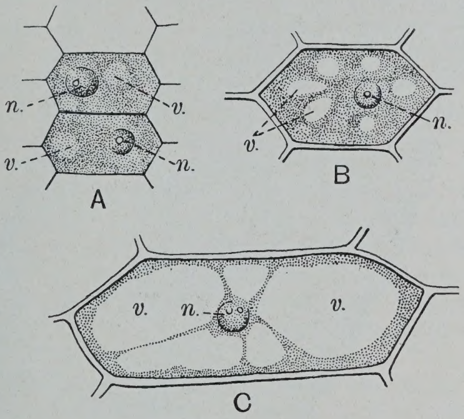


Fig. 92. *Young cells at different stages of growth.* A, very early stage; the cell walls are thin and the protoplasm fills the cell. B, the cell wall has thickened and vacuoles are appearing. C, older stage with large vacuole, protoplasm next to cell wall, and nucleus suspended in the middle. *n.* nucleus; *v.* vacuole.

You can see this process of cell growth in the photograph of a section cut through a young growing root tip (Fig. 93). Near the tip the cells are small and here they are filled with protoplasm. In this region the cells are dividing. Farther away from the tip the cells are larger. Here they are growing. Their protoplasm is increasing in amount and they are forming vacuoles by absorbing water. This and the next region make up the part in which the ink marks separated most in Exp. 10 (Fig. 91). In the next region farther back

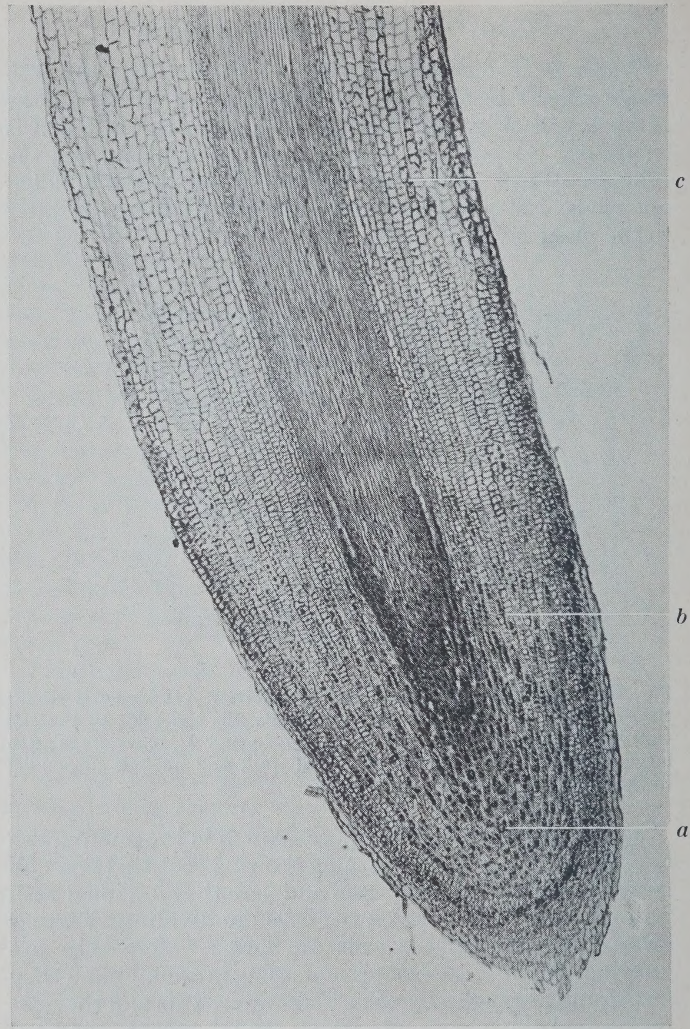


Fig. 93. *Tip of growing root.* This photograph, taken under the microscope of a thin section cut through a growing root, shows the successive stages in the growth of cells. *a*, young dividing cells filled with protoplasm; *b*, cells growing in size by the formation of central vacuoles; *c*, fully grown cells with large vacuoles.

growth of the cells goes on by more water being taken in, while the cell walls enlarge. Following the section still farther from the tip you see that the cells no longer get any bigger. Their growth in size has stopped.

GROWTH MOVEMENTS. When a seed germinates the plumule grows directly upwards and the radicle grows straight downwards, no matter which way up the seed may be lying in the soil (Fig. 88). The radicle grows towards, and the plumule straight away from, the earth. If you take a seedling and fix it so that radicle and plumule are horizontal, then after a short time you will find that the tip of the young root has bent and is continuing its growth straight downwards (Exp. 11), while the plumule will have done just the opposite. Evidently the directions of growth of both root and stem are controlled by the direction of *gravity*. Roots grow downwards and stems upwards. This is true not only of the radicle and plumule, but also of roots and stems later on than the seedling stage (Exp. 12). You often see this with cut flower stems of tulips or branches of lupins in a flower vase. They bend upwards.

But the direction of growth of stems and roots depends on other influences besides gravity, so that in nature they do not grow vertically upwards and downwards. On a windy coast the trees are often all inclined in one direction. The prevalent wind is responsible, since it not only actually bends the tree when young, but growth is slower on the windward side where evaporation is greater. The buds do not grow out on that side.

Gravity is one cause which directs growth of plants. *Light* is another. Stems bend *towards* light (Exp. 13). This is familiar to everyone from seeing potted plants placed in a window. The sunflower is so named because the flower head follows the course of the sun from morning until evening. The stem bends with the changing direction of the sun's rays. And roots if they are exposed bend *away* from light. Many leaves place themselves *across* the sun's rays.

The leaf stalks bend so that the leaf surfaces are perpendicular to the rays of light (Fig. 94).

It is obvious that these movements are of use to the plants. The responses of seedlings to gravity and light cause the radicles to grow down into the soil where the root hairs will find water and salts. At the same time the plumule growing upwards against gravity brings the young leaves to the light and air. Stems bending towards the light help photosynthesis in the leaves. This is further aided by the leaves placing themselves across the light rays, so that each part of the leaf surface gets a maximum of light. Often branches and leaves become arranged so that as far as possible no leaf is shaded by another leaf. You can see this in any garden.

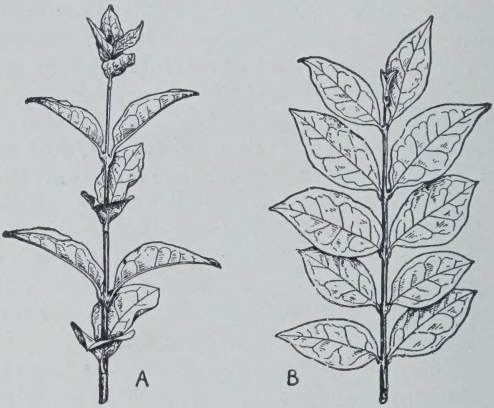


Fig. 94. *Privet branches.* A, from top of hedge, seen from the side; B, from side of hedge, seen from above. The leaves in B are attached to the stem as in A but their leaf stalks have twisted to bring the leaves perpendicular to the direction of the sun's rays.

The actual way in which these movements take place is by an *unequal amount of growth* on the opposite sides of stem or root. If a root lies horizontally, for example, its tip bends down in the direction of gravity by the upper part of the root growing more rapidly than the lower part. If you compare the part of the root which bent in Exp. 11 with the position of most rapid growth in Exp. 10, you will see that they are the same.

Not only gravity and light cause unequal growth. Touch may have the same effect. A number of plants are climbers. Some of these attach themselves to supports by *tendrils*. These are thin stems which coil round the branches of other plants (Fig. 95). Or they may be parts of leaves, as in the sweet pea and vetch. Tendrils are sensitive to touch (Exp. 14). When they touch an object they bend round it. Often the free part of a tendril, between the support to which it has attached itself and the plant, grows and coils itself like a corkscrew. Since it is impossible to make one spiral between two fixed ends, the coil is reversed in the middle. These coils act as springs, so that the climbing plant is not torn from its supports by wind.

WOOD. Stems and roots grow in length, but they also grow in width. Think how a *tree trunk* widens year by year. Now, if you examine a section across a tree trunk it looks quite different from the section of a sunflower stem cut to show the vascular bundles (Fig. 25). This is because, in a tree, the vascular bundles are not separate from one another, but they fill up the whole centre of the stem. Wood is nothing more or less than an immense vascular bundle.

There are two reasons why a tree needs so much vascular bundle. The first is that an immense *transpiration* current must move upwards all the time to supply the enormous number of leaves with water and nitrates. The second reason is that a tree depends for its *support* on the cell walls of the wood cells. Smaller plants, as you know, are kept stiff by the turgor of their cells (p. 68). But this is not sufficient to support the weight of a tree. It must have a rigid *skeleton* of wood.

ANNUAL RINGS. How does a tree trunk *increase in width*? The growing and dividing cells which add to the width are on the outside of the wood. They form part of the greenish layer immediately under the *bark* (Exp. 15). The bark itself (Fig. 96) is a dead deposit of *cork*. It prevents loss

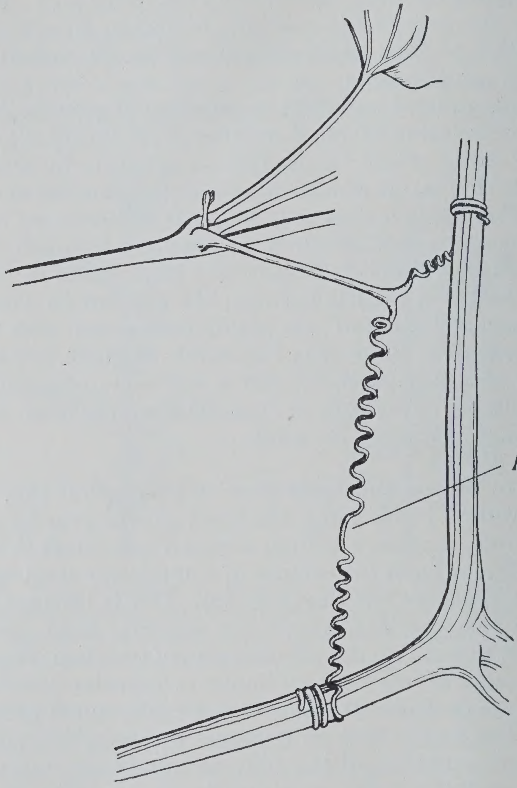


Fig. 95. *Climbing plant attached by tendrils* to another plant. The change in direction of spiral is seen at A.

of water. As the trunk increases in thickness the bark becomes too small and splits, new layers of cork being formed beneath the old ones. In the oak and elm the bark cracks without falling off, but in the plane it come off in flakes.

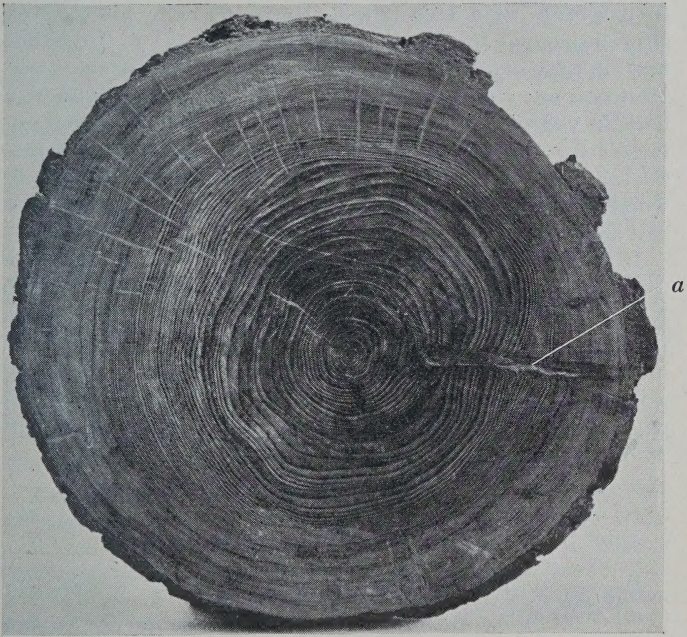


Fig. 96. *Section across a tree trunk.* The annual rings have varying widths according to the amount of growth each year. On the outside is the bark. The base of a branch (*a*) can be seen on the right.

As the cells underneath the bark divide, those on the inside are continually being changed into more and more wood cells with thick and rigid cell walls. But this increase in the wood does not go on equally all the year round. Growth slows down in winter, owing to the low temperature

(p. 186). In the spring it starts again, and large new wood cells are formed. As the season advances the new wood cells are smaller and smaller in size. In consequence of this a clear ring of wood is added each year.

These are called *annual rings* and you can easily see them in a section of a tree trunk (Exp. 16). The photograph (Fig. 96) shows by the differing thickness of the rings that the amount of growth was different in the various years. You can see also how a branch started to grow out in a certain year, and how the base of the branch has been enclosed by the growth of the stem in succeeding years. Sections across the bases of such branches are *knots* in wood. On the outside of the trunk in the photograph you can see the bark.

It is quite easy by counting the rings to tell the *age* of a tree (Exp. 17). Some trees are immensely old. In the Natural History Museum in London there is a section through a huge trunk with all the important events in history from the reign of the Emperor Justinian I in A.D. 557 onwards marked on the corresponding annual rings. This tree grew in California. When it was felled in 1892 its rings showed that it was 1335 years old.

## PRACTICAL WORK

*Exp.* 1. Soak broad beans in water for a day or two and study their structure.

*Exp.* 2. Cut a bean cotyledon in two and test its surface for starch with a solution of iodine in potassium iodide.

*Exp.* 3. Soak beans in water for twenty-four hours. Wash them in fresh water and plant them in moist sawdust or bog moss in a flower pot. Examine them to see stages in germination, and growth curvatures of root and stem.

*Exp.* 4. Cut open a castor-oil seed to see the reserve food and the embryo. Rub the split seed on paper to show its oily contents.

*Exp.* 5. Study germinating castor-oil seeds.

*Exp.* 6. Soften maize grains by soaking them in water and cut them in two to see the embryos.

*Exp.* 7. Study germinating maize.

*Exp.* 8. Take four tall beakers and put blotting paper and then cotton-wool in the bottom of each. Put dry barley grains on the cotton-wool in beaker (i), and grains which have been soaked for twenty-four hours into beakers (ii), (iii) and (iv). Half fill the beaker (ii) with boiled and cooled water and cover the water surface with oil. Pour unboiled water into beakers (iii) and (iv) so that the cotton-wool is soaked but the seeds are not under the water. Surround the lower part of beaker (iii) with a tin containing ice with flannel outside the tin. Cover the mouths of the beakers with perforated pieces of cardboard and see that all four beakers are lighted to the same extent. Add water to (iii) and (iv) daily so that the seeds never become dry. Compare the amount of growth of seedlings in the four beakers. In (i) the seeds have no water, in (ii) they have no oxygen. In (iii) and (iv) water and oxygen are present, but (iv) is at a higher temperature than (iii).

*Exp.* 9. Make another experiment like No. 8 with seeds on wet cotton-wool in two beakers. Keep one beaker in light and the other in darkness.

*Exp.* 10. Fix bean seedlings with straight roots by pins through the seeds to the under side of the cork of a wide-mouthed jar which is lined by wet blotting paper. With a stretched thread dipped in waterproof Indian ink make cross marks at equal distances apart on the root. After a day or two look at the ink marks.

*Exp.* 11. Soak beans in water for twenty-four hours and plant them in moist sawdust. When the roots have grown to about ¾ inch in length pin the seeds to the under side of a cork in a wide-mouthed bottle which is lined with blotting paper and has a little water in it. Notice how the roots curve towards the earth.

*Exp.* 12. Grow a broad bean plant in a pot. When the stem is about five inches long put the pot on its side in the dark. After some hours the end of the stem will have curved upright.

*Exp.* 13. Sow cress or other seeds. When the young stems have grown out, put the pot near a window. The stems bend towards the light.

*Exp.* 14. Lightly stroke the lower side of the tendril of bryony with a match once or twice. Within a minute or two it bends at the point touched. Examine various kinds of tendrils.

*Exp.* 15. Strip off the bark from the branch of a tree to see the greenish layer between bark and wood.

*Exp.* 16. Examine a section of a tree trunk with a lens.

*Exp.* 17. Find the age of a branch by counting its annual rings.

## *CHAPTER XIV*

# BUDS AND BULBS

STEMS. Flowering plants are made up, as you know, of *roots*, *stems* and *leaves*. The stem with the leaves on it is known as the *shoot*. The shoot may be long, or it may have a very short stem. The daisy and the dandelion are examples of plants with very short stems. The result is that the leaves are all very close together.

The larger flowering plants are either *trees* or *shrubs*. Trees have one main stem. Shrubs are smaller than trees and they are branched down to their base. Both trees and shrubs have *woody* stems. *Herbs* are smaller plants with soft stems that are *not woody*. You will remember the different ways in which herbaceous and woody plants keep their stems rigid (pp. 68 and 193).

LEAVES. The leaves, which are of various shapes according to the plant, come off the stems in different fashions. Sometimes they are *in pairs* opposite one another. When this is the case each pair is usually at right angles to the pair above and below it. You can see this arrangement in the dead-nettle and in the upright branches of the privet (Fig. 94 and Exp. 1). This helps to prevent one leaf being shaded by another (p. 192). In most plants, however, the leaves come off the stem *singly*, not in pairs. This is the case, for example, in grasses (Fig. 102) and in the elm.

BUDS. If you cut a bud in two you will see a lot of small young leaves crowded together (Fig. 97). As the bud grows out into a branch these young leaves become separated from one another at the same time as they increase in size. Looking at the bud section again, you can see that the young leaves at its tip are the smallest. They are the youngest. It follows that the leaves towards the end of the shoot into which the bud grows are younger than the leaves towards its base.

There is a bud at the end of each shoot, whether it be the main shoot of a plant or any of the branch shoots. This is a *terminal bud*. In addition, there is a small bud at the base of every leaf on the plant (Exp. 2). These buds are found between the bases of the leaf stalks and the stem. Each of these buds is placed in what is known as the *axil* of the leaf. They are therefore called *axillary buds*. Fig. 98 shows axillary buds and Fig. 97 is a section cut through two of them.

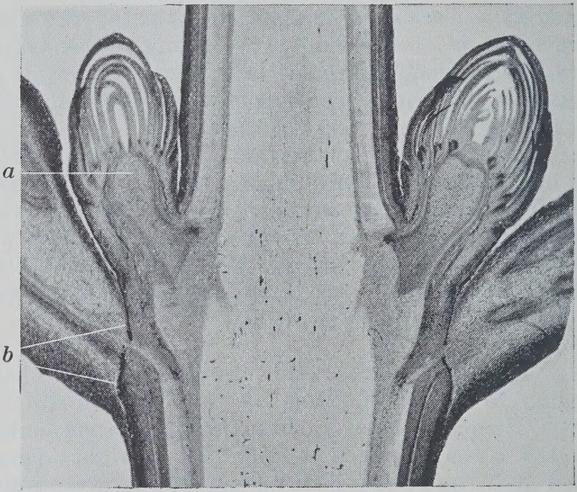


Fig. 97. *Axillary buds and leaf fall.* This is a photograph of a section through a sycamore shoot. The buds (*a*) are in the axils of leaves. Scale leaves, young foliage leaves and vascular bundles can be seen in the buds. The old leaf bases each have a layer of cork (*b*) almost right across them preparatory to the leaves falling in autumn.

All the buds on a plant, other than the terminal buds at the ends of the shoots, are borne in the axils of the leaves. But only some of the axillary buds grow out into branch shoots. Very many of them never develop.

TWIGS. Twigs are small branches of trees. Quite a lot about the past history of a twig can be found out by looking at it in winter when it has lost its leaves. As an example we can take a sycamore (Fig. 99 and Exp. 3) or a horse-chestnut twig.

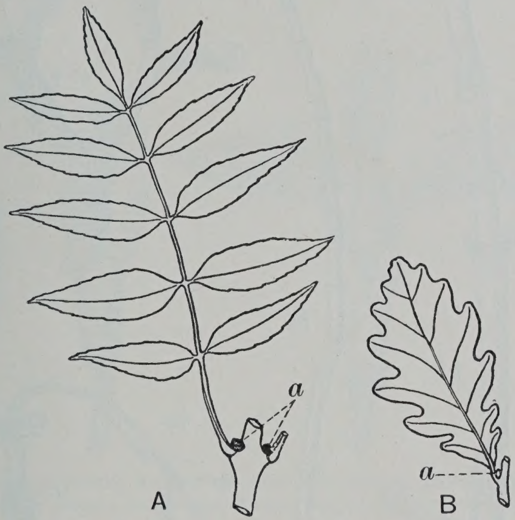
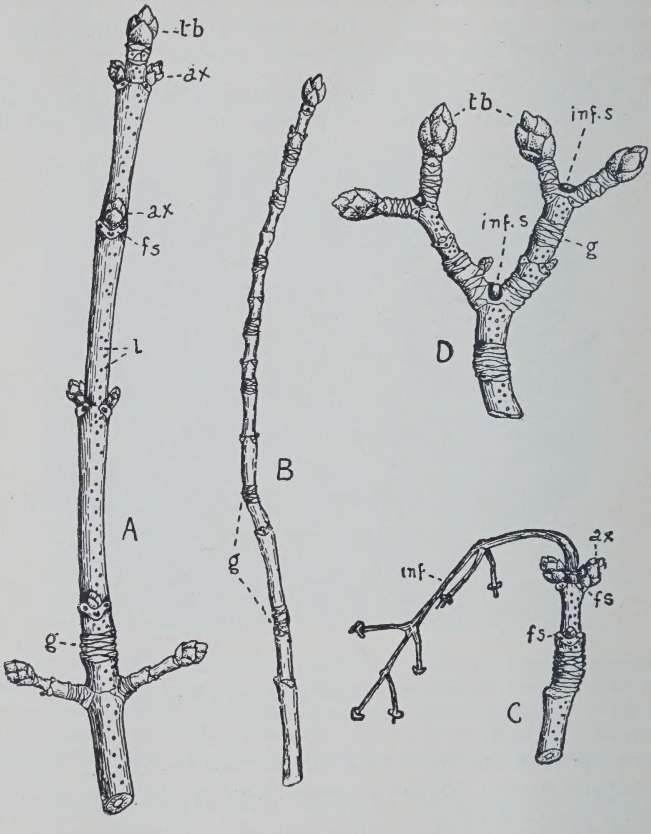


Fig. 98. *Leaves and axillary buds.* A, ash; B, oak. *a*, axillary buds.

On the thin bark (p. 194) are seen numerous spots, the *lenticels*. Bark, you recollect, is waterproof, keeping the stem from drying up. But oxygen must get in for the respiration of the living cells in the stem. The oxygen gets in and carbon dioxide comes out through these holes, the lenticels.


tb
ax
ax
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l
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A
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Fig. 99. *Twigs of sycamore.* A and B are ordinary twigs with monopodial branching. B is a starved twig. C and D are flowering twigs with sympodial branching. *ax*, axillary bud; *fs*, scars of ordinary leaves; *g*, scars of bud scale leaves; *inf*, stem with remains of last year's flowers; *inf.s*, scar of same; *l*, lenticels; *tb*, terminal bud.

At the tip of the twig is a *terminal bud*. It is surrounded by brown *scales*, which are really modified leaves. They are packed close together and are waterproof. Their purpose is to protect the young green leaves inside the bud from injury and from drying up, for the tree does everything possible to prevent transpiration in winter (p. 70).

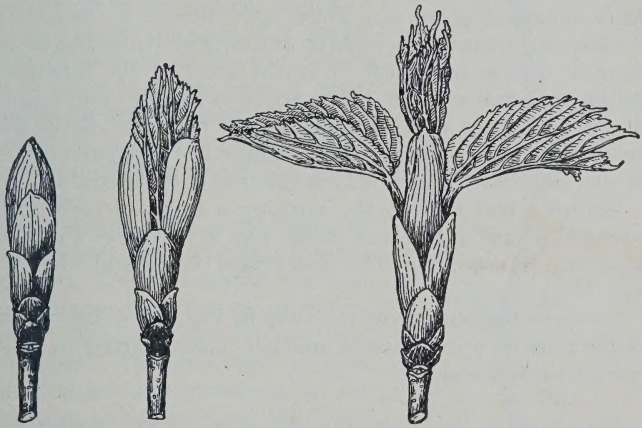

Fig. 100. *Opening buds of sycamore.* The young green leaves are seen coming out from between the brown scale leaves.

Different trees have buds of different sizes, shapes and colours. Those of the horse-chestnut, for example, are large, dark coloured and sticky. It is possible to recognize common trees in winter not only by the general shape of the branches but also by the appearance of the buds (Exp. 4).

If you now cut a terminal bud in two (Exp. 5) you will easily see how the scale leaves enclose the small and young green leaves. In the spring the end of the stem, in the middle of the bud, will lengthen and the green leaves will expand and grow (Fig. 100). Some of the terminal buds, when cut open, show the beginnings of a flower inside, as well as leaves. It is quite clear now that leaves and flowers are already formed inside the buds by the time winter is over. The warmth of spring causes the buds to open and you can readily understand how it is that the leaves and flowers of trees appear so suddenly in spring, since everything is ready inside the buds.

On the sycamore twig will be found several pairs of *axillary buds* (Fig. 99, *ax*). These were formed in the axils of the leaves, but as we are looking at a twig in winter the leaves have of course fallen off. But the *scars* of the fallen leaf stalks are plain enough. They are seen to be in pairs opposite one another and at right angles to those above and below. On each scar are spots. These are the broken ends of the vascular bundles which entered the leaf stalk.

Before a *leaf falls* in the autumn a layer of *cork* forms across the base of the leaf stalk. Fig. 97, *b* shows this cork layer almost complete. The cork closes the wound when the leaf drops off.

Towards the bottom of the twig in Fig. 99, A two of the axillary buds, opposite one another, have started to grow out into side *branches.*

ANNUAL GROWTH OF TWIGS. Just above the pair of young side branches is a *ring of scars* going right round the stem (Fig. 99, A, *g*). When the terminal bud opens in the spring, its protecting scale leaves fall off, leaving scars on the stem. This ring of scars round the twig was made by the scale leaves of last year's terminal bud. Between the time when these scars were formed last spring and now, the twig has grown out to the present terminal bud.

On twigs you can find a number of these rings of scars, and by counting them the *age of the twig* is found. Not only this, but the different lengths of twig between the rings of scars give the amount of growth in each year.

Suppose that an axillary bud on a sycamore twig has started to grow out. Normally its growth each year will be less in amount than the growth of the main twig. But suppose now that the end of the main twig is cut off. There is therefore no longer a terminal bud to continue the growth of the main shoot. The result is a greater rate of growth of the side branch. It grows out and takes the place of the cut-off main branch. Fig. 101 shows this in the case of a beech twig. The scars of the bud scales on it show that the branch grew slowly for three years. Then the end of the main shoot was cut and the branch commenced to grow rapidly.

You know that very many of the axillary buds on a plant never develop. This is because there is not enough food for all of them. Some of them develop as side branches. The rest are reserve buds which can grow out to replace a terminal bud that has been lost. Rose trees are *pruned* by the gardener. This means that terminal buds are cut off so that a number of axillary buds shall grow out and turn into short branches bearing flowers.

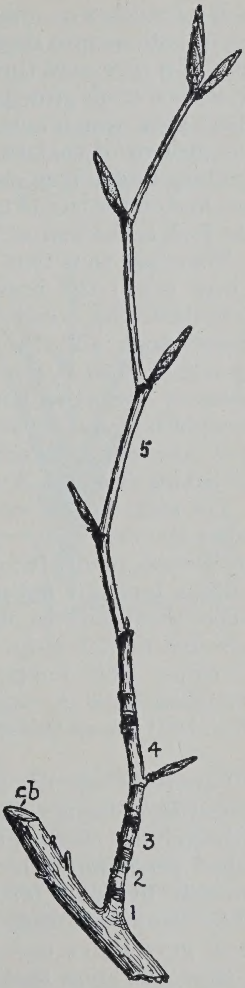

Fig. 101.

Fig. 101. *Twig of beech* with sympodial zig-zag branching. 1–5, portions formed in successive years. Each portion is separated from the next by a ring of scars of bud scale leaves. In the fourth year the main branch was cut at *cb*, after which the side branch grew more rapidly.

Branching. Some buds develop into shoots with leaves, others into shoots bearing *flowers*. When a terminal bud of a sycamore turns into a short stem with flowers on it, it then stops growing. Later on the flowers fade and the short stem which bore them drops off. The following year the growth of that twig is continued by the next pair of axillary buds. This produces the forked twigs which you can find on the tree (Fig. 99, D and Exp. 7). In the middle of the fork is the scar of the flower stem.

There are thus two ways of branching in the sycamore. There is (1) the branching of the flowering twigs just described. This is called *sympodial* branching. The terminal shoot stops and the next axillary buds continue the growth (Fig. 99, C, D). And there is (2) the branching of the ordinary twigs without flowers. Here the twig grows straight out year by year and the side branches are shorter than the main branch. This is the *monopodial* type of branching (Fig. 99, A).

The pine, like the sycamore, branches monopodially, but many trees are of the sympodial type, and so are numerous herbaceous plants (Exp. 8). In many plants, of course, the axillary buds are not in pairs opposite one another. Then, when the plant is one with sympodial branching, the terminal branch stops growing and the next axillary bud develops. This happens again and again so that the branches have a zig-zag appearance. The beech twig (Fig. 101) shows this clearly.

Length of life. Trees live for years or even for centuries, growing all the time. But herbaceous plants have a shorter life. Some of them live for several years. These are called *perennials*. The daisy is an example. Others, the *annuals*, live only for part of a year, like the groundsel. They form seeds each year and then die. Next year the seeds grow into a new generation of plants.

Now, you know that *trees* have to face hard conditions in *winter*. One of their difficulties is that they risk being unable to absorb enough water through their roots to replace the water transpired. They face the problem either by having evergreen leaves with thick cuticles, like the pine and holly, or by losing their leaves (p. 70).

To get over the difficulties of winter *annual herbaceous plants* die off, leaving their thick-walled seeds to tide over the cold season. Many *perennials* adopt another method: the shoots above ground die off in the autumn, while underground stems and roots live on until next spring.[1] Then buds on the underground stems grow up into new shoots above ground. The horizontal underground stems are called *rhizomes*. You will find them, for example, in the iris, in Solomon's seal and in certain sedges (Fig. 102 and Exp. 9).

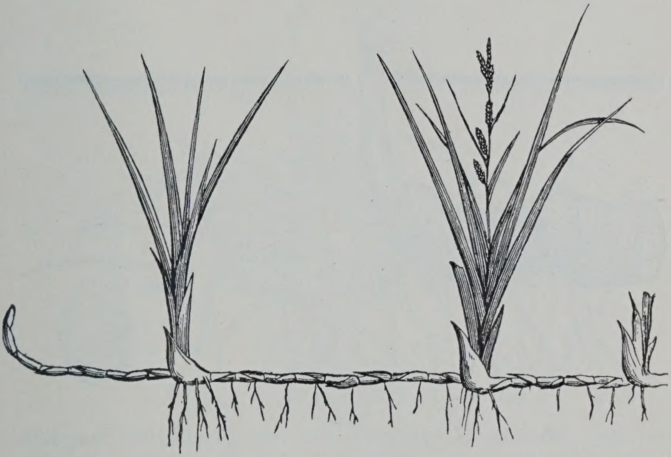

Fig. 102. *Rhizome of sedge*, sending up shoots at intervals. Scale leaves are seen on the rhizome.

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[1] All perennial herbs do not die down in the winter. Grass keeps its leaves.

That rhizomes are really stems, not roots, is clear since they bear leaves. These are not green leaves: in the dark they can develop no chlorophyll (p. 187), nor would they have any use for it. They are merely *scales*. But there are, as usual, buds in the axils of these scale leaves. Often the terminal bud of a rhizome grows up above ground in the spring, while an axillary bud continues the underground stem (Fig. 103). This is a case of sympodial branching.

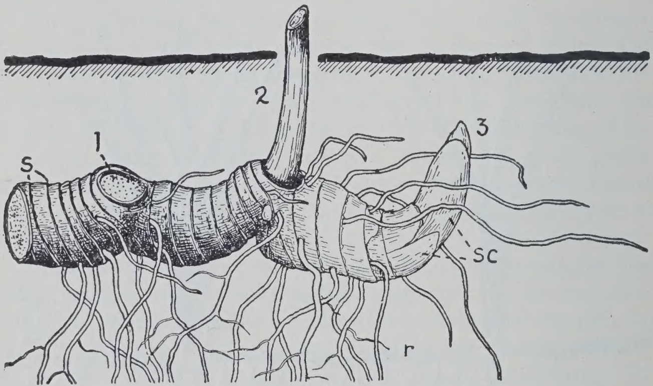

Fig. 103. *Rhizome of Solomon's seal*, with sympodial branching. 1, scar of last year's upright shoot; 2, this year's shoot; 3, terminal bud of next year's shoot. *r*, roots; *s*, scars of old scale leaves; *sc*, scale leaves.

Food stores. Those perennials having shoots above ground which die down in the winter store food in their underground parts. It is mostly starch, with some protein. The food is prepared as usual in the leaves above ground, and then sent down in solution to the storage place. This storehouse may be the *rhizome*, for instance in the case of the iris and Solomon's seal. Sometimes branches of the stem are very swollen with food. Then they are called *tubers*. Potatoes are such swollen stems (Fig. 104).

The "eyes" of potatoes are scale leaves with their axillary buds. Next season these grow out into new shoots (Exp. 10).

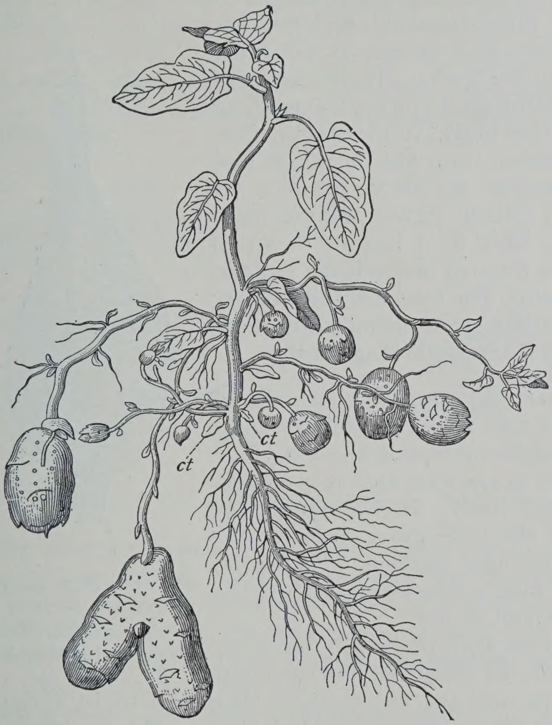

Fig. 104. *Young potato plant. ct*, cotyledons. Tubers can be seen at the ends of branches with "eyes" on them.

Instead of an underground stem it may be a swollen *root* that does the storage. The carrot and turnip are cases in point (Exp. 11). Or again, *leaves* may store the food, in which cases we get *bulbs*, like the onion. A tulip bulb cut in two is seen to be a short flat stem with a few fleshy leaves surrounded by scaly protective leaves, and roots below (Fig. 105 and Exp. 12). In the centre is a terminal bud. This bud consists of a young shoot with foliage leaves[1] and the beginnings of a flower. It will grow up in the spring. In the axils of the fleshy food-storing leaves there are other buds. In the spring, after the shoot from the terminal bud has grown up above ground, its green foliage leaves prepare more food. This food is sent down to one or more of the axillary buds in the bulb. The leaves in the axillary buds then swell up and form more bulbs for the following winter.

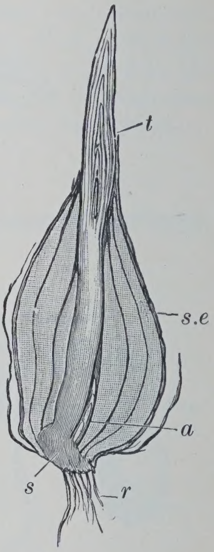

Fig. 105. *Bulb*, cut in two. *a*, axillary bud; *r*, roots; *s*, short stem; *s.e*, scale leaves; *t*, terminal bud.

THE REASON FOR FOOD STORES. When an embryo plant grows from a seed it needs the food stored in the seed until it can begin to feed itself. In the same way when the buds grow out from the underground parts of a perennial herb food is necessary to start the new shoot in life.

Plants with bulbs are found especially in countries like southern Europe and the Cape, where there is a moist spring and a hot, dry summer. The plant starts each new season with a store of food for rapid growth and flowering. After flowering is over, the foliage leaves make food which is at once stored in the bulb to be used for next year's growth, and then the foliage leaves die down as the summer advances.

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[1] Normal green leaves are called *foliage leaves* to distinguish them from specialized leaves such as scales, cotyledons, food stores or flower parts.

Vegetative reproduction. You know how the bracken fern spreads itself over wide areas of ground (p. 103). Flowering plants with *rhizomes* do the same thing. The older parts of the rhizome die off and each season fresh shoots grow up. It may even be much more often than once a season., Many grasses have rapidly growing rhizomes which send up new plants above ground at frequent intervals (Fig. 102).

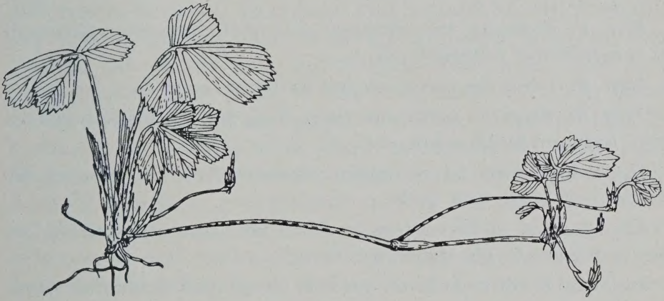

Fig. 106. *Strawberry plant* showing runners giving rise to new plants.

Other plants spread by horizontal *stems* lying *on the surface* of the ground. These are seen in the strawberry plant and the creeping buttercup. They are called *runners* (Fig. 106 and Exp. 13). At intervals buds on the runners grow into new plants. They become independent of the parent when the runner dies off.

When a branch of a potato plant has swollen up into a *tuber*, the tuber becomes detached from the plant as the latter dies down in the autumn. Next year one or more new potato plants grow out of the tuber.

The new *bulbs* formed from axillary buds in the old onion or tulip bulb become detached from the old bulb as the latter shrivels when all its food has been used up by the plant above. Next season the new bulbs each start life as a new free plant.

All these ways of forming new plants from parts of the old are known as *vegetative reproduction*. This is really the production of a new individual plant, not from a single cell, the spore or the zygote, but from a bud on the plant body composed of many cells. You can compare this method of reproduction with the budding of *Hydra*.

## PRACTICAL WORK

*Exp.* 1. Examine the arrangements of the leaves on the stem in a number of different plants.

*Exp.* 2. Look for terminal and axillary buds.

*Exp.* 3. Study a sycamore twig, look for lenticels, terminal bud, axillary buds, scars, etc.

*Exp.* 4. Learn to recognize common trees in winter by branching, bark, and buds.

*Exp.* 5. Cut in two a terminal leaf bud and a flower bud of the sycamore to see their structure.

*Exp.* 6. Look closely at various twigs and determine their age. Compare the amount of growth in various years.

*Exp.* 7. Study a sycamore twig which has flowered.

*Exp.* 8. Examine a number of different plants and make out the type of branching in each.

*Exp.* 9. Examine rhizomes.

*Exp.* 10. Find how tubers grow on a potato plant. Cut a potato in two and test the cut surface with iodine for starch. Examine the "eyes", and the buds in sprouting potatoes.

*Exp.* 11. Examine carrots and turnips to see that they are swollen roots.

*Exp.* 12. Slice a bulb in two and study its structure. Examine sprouting onions.

*Exp.* 13. Look at a strawberry plant to see the runners.

## *CHAPTER XV*

# THE ANIMAL KINGDOM

### I. THE DIFFERENCES BETWEEN ANIMALS AND PLANTS

IF a person who is not a biologist is asked what are the differences between an animal and a plant he will probably say first of all that there is no resemblance. Then he may give a list of obvious differences. But when you look more closely into these distinctions most of them break down—you know of exceptions to them. Most animals, for instance, *move* about while plants are anchored to one spot. Most animals must move to find their food, whereas the food of plants is everywhere in soil and air. But think of *Chlamydomonas* and of a coral. Then, plants have *chlorophyll* and make starch with its aid, while animals have no chlorophyll. But fungi and bacteria have none either. Plants take in their *food* in solution, animals eat solids and consequently have a mouth and alimentary canal. Yet the sundew catches flies, while the malaria parasite and the tapeworm feed on solutions in the bodies of the animals in which they live as parasites.

The obvious distinctions between plant and animal seem to break down. Yet there are real differences. First of all the animal generally has a body with a definite size and *shape*. Not so the plant.[1] Parts of it may have a settled form, like the flower, but the whole plant branches in this direction and in that. This is true equally of a mould, a fern or a bush. Animals, then, are definite *individuals*, but it is difficult to say where an individual plant begins and ends when it is spreading by runners like a strawberry plant.

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[1] But *Amoeba* has a changing shape, while *Chlamydomonas* has a fixed one.

It is quite true that most animals move about while only the lowest plants do so. As a result the higher animal at any rate has sense organs to know what it will meet, and a *nervous system* with a brain to command its movements.

And there is another, perhaps the most important, difference. For the other distinctions depend on it. Plant cells have rigid *cell walls*, animal cells have none. What is the result of this? Plant cells absorb water by osmosis until they are turgid—blown out by osmotic pressure against the outer cover of the cell wall. Animal cells if they did this would burst, for they have no cell wall. So *Amoeba* and *Paramecium* have contractile vacuoles. And the cells of the higher animals are bathed in blood and body fluids which contain the same amount of dissolved substances as their protoplasm. Blood and protoplasm therefore have the same osmotic pressure, so the cells neither swell nor shrink. Thus the lack of cell walls in the animals is dealt with. And it is worth while. For as a result the animal can move. If there were a hard wall round each cell, no muscles could exist. For in order to work, a muscle must change its shape. And the existence of muscles leads to the existence of nerves and a brain to control them. So really the cell wall or its absence accounts for some of the chief differences between animals and plants.

## II. CLASSIFICATION

We divided plants roughly into lower and higher, less complex and more complex in structure. More exactly, we put them into groups: *bacteria*, the *fungi* (moulds and mushrooms), the *algae* (*Chlamydomonas*, *Spirogyra* and seaweeds), *mosses*, *ferns*, *pines* and *flowering plants*. Plants included in each group are more or less alike in structure.

In the same way animals are classified into groups, some with a simple structure, some more complicated. The big groups of animals are called *phyla*. Thus the one-celled animals (*Amoeba*, *Paramecium*, etc.) belong to the phylum

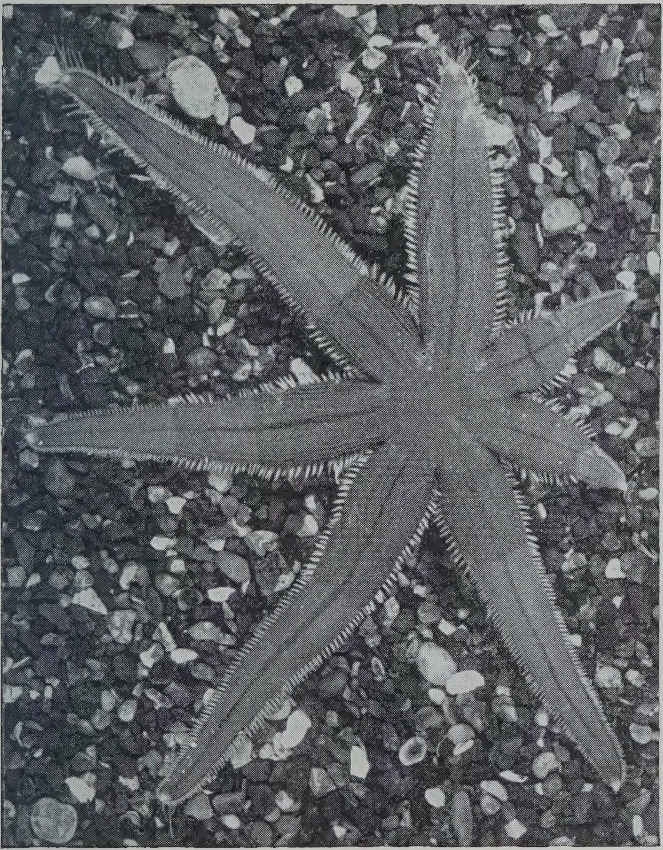

Fig. 107. *Living starfish.* Some of the arms have been broken off and new arms, lighter in colour, are regenerating. (D. P. Wilson.)

*Protozoa*. *Hydra* and corals are in another phylum. The *earthworm* and its relations are in a third.

The *starfish*, often found in rock pools at low tide, is a member of yet another phylum. When one of the arms of a starfish is broken off it grows a new one (Fig. 107). Compare this with regeneration in *Hydra* (p. 117). The *sea-urchin* (Fig. 108), also living in the sea on our coasts, belongs to the same phylum as the starfish. We have met it already in connection with fertilization (Fig. 50) and the cell division of a fertilized egg (Fig. 51).

The frog and man are in the phylum of *vertebrate animals*. The insects do not form a phylum by themselves. They are grouped together with certain other animals not very far away from them in structure. These are the spiders and the crustaceans. All three of these groups (or *classes*, as they are called), *insects*, *spiders* and *crustaceans*, together make up the phylum of *arthropods*.

Every animal and plant is different from its neighbours. Even in a family, brothers and sisters are not alike. Yet there are groups of animals or plants in which all the members are more or less alike. These are called *species*. You may rightly ask, how are we to limit species? Do all kinds of horses belong to the same species, and does the species include donkeys or not? The way the question is decided is this: when members of a group of animals can breed with one another and have offspring that are fertile,[1] then they form part of one and the same species. All races of horses breed together and have fertile offspring. But the mule, the result of a horse-ass cross, is sterile. Therefore horse and ass are put in different species.

Each species has a scientific name, or rather two names. The ass, for example, is called *Equus asinus*. The second name is that of the *species*, the first is the name of the *genus* to which the animal or plant belongs. Species which are near to one another in structure are grouped together as *genera*. The name of the genus has a capital letter, that of the species a small letter. The names of genus and species are always printed in italics. Thus the common frog is called *Rana temporaria*. Its species is *temporaria*. It belongs to the genus *Rana*. The genus includes several species, of which another is the edible continental frog, *Rana esculenta*. The common white dead-nettle is *Lamium*

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[1] *Fertile* means that an animal or a plant can reproduce its kind, *sterile* that it cannot do so.

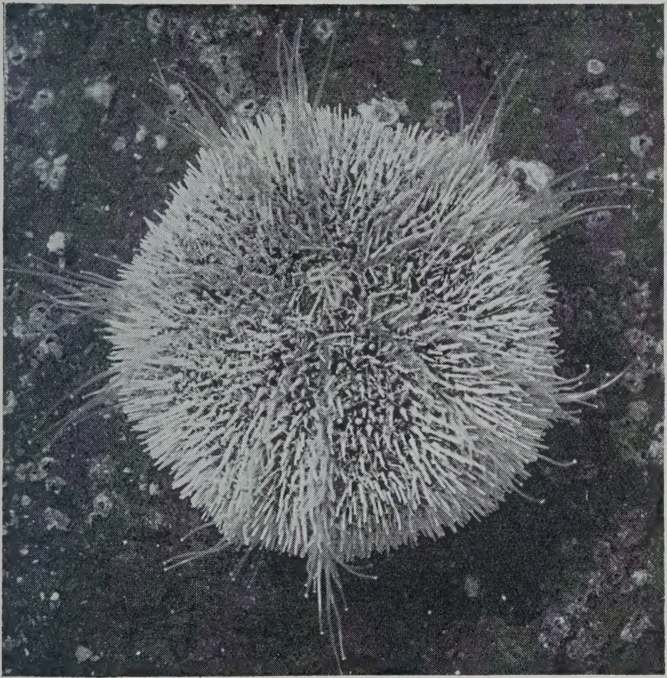

Fig. 108. *Living sea-urchin*. This animal measures 4 inches across. The numerous protective spines are seen, and the suckers by means of which the animal moves. (D. P. Wilson.)

*album.* The red dead-nettle is *L. purpureum* and the yellow archangel is *L. galeobdolon.* These are three species of the genus *Lamium.* This way of giving a double name to every species of animal and plant, the name of its genus and of its species, was started by Linnaeus in the eighteenth century. Species are grouped into genera, and these into families, classes and phyla.

## III. THE CRAYFISH

Crabs, prawns, shrimps, lobsters and river crayfishes are all *crustaceans*, and they are nearly related to one another. The body of a crustacean such as the crayfish (Fig. 109) is covered by an armour made of *chitin* (Exp. 1). This armour is for protection and it is a skeleton. Muscles are attached to it in the same way as in an insect (Fig. 57 and Exp. 2). In order to grow, the crayfish must shed its armour from time to time, since the chitin cannot expand. The shell splits along the back and the animal wriggles out. Its body is now soft for a day or two, and during that time it grows, hiding itself from enemies.

The body is *segmented* and most of the segments bear a pair of jointed limbs. In front, the segments of the body are rigidly joined together. This region includes the *head* with the *thorax* behind it. It is covered on top by one piece of armour called the *carapace.* Behind the thorax, the segments are separate and movable on one another, having thin armour between each. This region is called the *abdomen.* The crayfish walks forward slowly on its legs, but when frightened it darts backwards quickly. It does this by suddenly bending the abdomen downwards, using the tail fans as paddles.

On each side of the body, above the walking legs, the carapace overhangs a space, something as a lean-to roof might do. This space contains the breathing organs or *gills.* These are numerous finger-like outgrowths. Some are attached to the sides of the body, others to the innermost

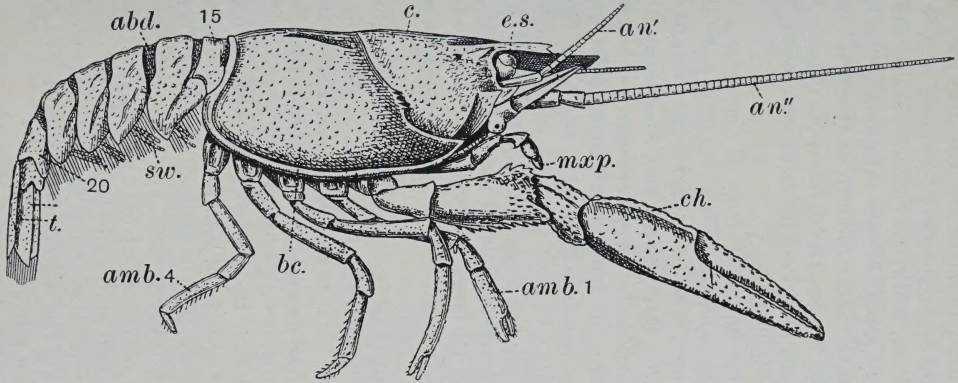
abd.
15
c.
e.s.
an'
an"
mxp.
sw.
20
ch.
t.
amb.4
bc.
amb.1

Fig. 109. *Crayfish.* *abd.* abdomen; *amb.*1, first walking leg; *amb.*4, fourth walking leg; *an'.* first antenna; *an''.* second antenna; *bc.* cover of gills; *c.* carapace; *ch.* claw; *e.s.* eye; *mxp.* third foot-jaw; *sw.* appendage of abdomen; *t.* tail fan; 15, 20, first and last segments of abdomen.

joints of the limbs. The blood circulates in these gills, and through their thin walls dissolved oxygen passes from the water into the blood, while the carbon dioxide diffuses out.

On the head are a pair of *eyes* on movable stalks. These eyes are made on the same pattern as those of insects. The way they see will be described later on (Chap. XVII). On the head there are also two pairs of *antennae*. These are for feeling and smelling.

The crayfish has nineteen pairs of *appendages*. The first two pairs are the *antennae*. Then come a pair of jaws or *mandibles*, two pairs of *maxillae* and three pairs of *foot-jaws*. After these are the large *claws* and four pairs of *walking legs*, followed by six pairs of *appendages on the abdomen*.

We will look into the structure of three of the appendages more closely. The *mandibles* (Fig. 110 and Exp. 3) on either side of the *mouth* are seen to have strong biting edges. There is a small jointed feeler or palp attached. Crayfishes feed mainly on dead animals. Indeed, like crabs, shrimps and lobsters, they are largely scavengers. The food is caught in the claws and torn up by foot-jaws, maxillae and mandibles.

The *second maxilla* of each side has an inner thin flat part to help in dealing with the food, and a plate on its outer side projecting backwards and forwards. This plate may be called the *baler*. It moves rapidly all the time and bales water out of the space in which the gills lie. In this way water streams in over the bases of the walking legs, passes over the gills and comes out forwards near the mouth. Thus the gills are continually supplied with fresh water containing dissolved oxygen (Exp. 4).

Each member of the *third* pair of *foot-jaws* has a large jointed inner branch and a small outer feeler or palp. This feeler and those of the other foot-jaws are continually flicking and testing the water. On the bottom joint of this third foot-jaw is a gill.

The first two of the four pairs of *walking legs* have small claws on them. The *appendages of the abdomen* have each two branches. The *eggs* of the female are carried attached to them until the young hatch out. In prawns these appendages are used for swimming.

When an appendage is seized by an enemy the crayfish breaks it off. Later on a new appendage is grown which becomes bigger at each moult. Compare regeneration in *Hydra* (p. 117), the starfish (p. 216) and the lizard's tail (p. 119).

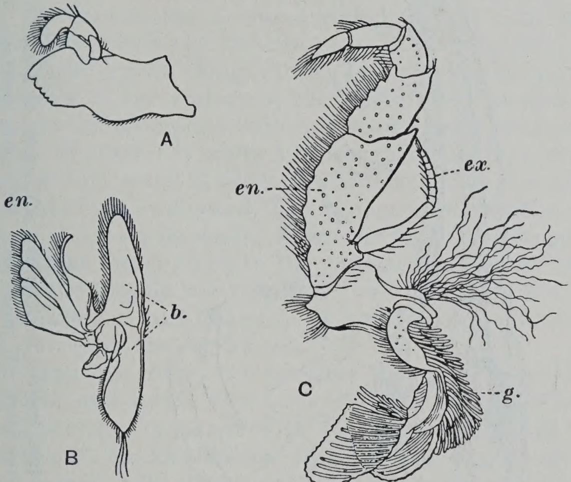

Fig. 110. *Mouth parts of crayfish.* A, mandible with palp and cutting edge. B, second maxilla; *b.* baler; *en.* inner flat part. C, third foot-jaw; *en.* inner branch; *ex.* palp; *g.* gill.

A dissection (Exp. 5) shows the *heart* lying above the other organs (Fig. 111). The blood system is on a different plan from that either of an earthworm or of a vertebrate animal. The blood is not confined to blood vessels. The heart, it is true, pumps blood into *arteries*. You can see these going forwards and backwards from the heart. But

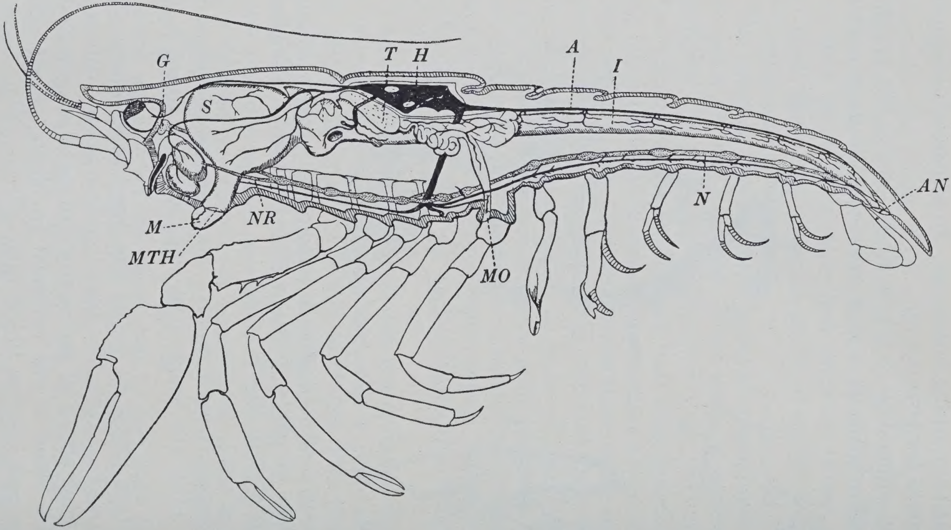

Fig. 111. *Anatomy of crayfish.* *A*, artery leading backwards; *AN*, anus; *G*, ganglion in head, just behind the eye; *H*, heart showing openings; *M*, mandible; *MO*, male opening; *MTH*, mouth; *N*, nerve cord with ganglia; *NR*, nerve ring round gullet; *S*, "stomach"; *I*, intestine; *T*, testis.

the blood leaves the arteries to flow through all the spaces between the organs, instead of going through capillaries. After passing through the gills it arrives back at the spaces around the heart. From there the blood is sucked into the heart through six openings with valves, and then pumped out into the arteries again. The blood has no haemoglobin in it. Instead it has a *blue*-coloured *protein* containing *copper*. This serves the same purpose as haemoglobin.

The most obvious things in the dissection are the powerful *muscles* of the abdomen, the large *liver*, the *testes* or *ovaries* according as it is a male or a female, and the so-called *stomach*. The latter is really a chamber in the front end of the alimentary canal in which the food is further chewed up after it has been swallowed. This stomach mill has movable teeth of chitin on its walls. From the mill the alimentary canal can be traced back to the *anus* on the last segment.

If all the organs are removed from the dissection the *nervous system* is seen (Exp. 6). It is obviously built on the same plan as in the earthworm.

You can see from the outside that the crayfish is *segmented*, and inside the body the nerve ganglia show segmentation. Compared with the earthworm, however, the segments are less like one another. The crustacean has a more complicated structure than the worm, and different segments are specialized for different jobs.

## IV. OTHER CRUSTACEANS

PRAWNS AND SHRIMPS. These are marine crustaceans very like the crayfish in build. Like the frog they can change colour. When on a dark background they go dark in colour and when they move on to light-coloured stones or sand they become pale (Fig. 112). These colour changes may make them less visible to enemies. The colour changes are due to colour cells as in the frog (Fig. 21). Crayfishes change colour under the same circumstances as prawns and shrimps, but the change is less marked (Exp. 7).

CRABS. The crab is like a crayfish or lobster in which the abdomen is very short and is tucked in under the thorax (Exp. 8). The young of crabs have the abdomen sticking out (Fig. **115**, *a*).

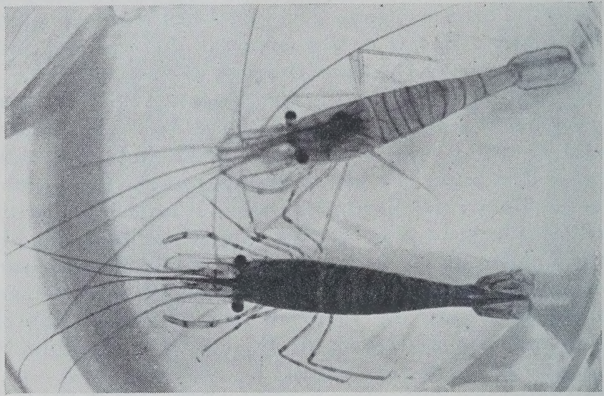

Fig. 112. *Colour change of prawns.* One had been on a dark-, the other on a light-coloured ground for half an hour. (E. M. Stephenson.)

FRESHWATER SHRIMPS. These crustaceans are not closely related to true shrimps. Fig. **113** shows what they look like. The segments of the thorax are separate, not joined together as in crayfishes, shrimps and crabs (Exp. 9). Similar animals, called *sandhoppers*, live on the sea shore, using some of their appendages for jumping.

*DAPHNIA.* This so-called "water flea" is a small crustacean living in ponds (Fig. **114** and Exp. 10). The carapace is flattened from side to side and overhangs the limbs. *Daphnia* swims laboriously, using its second pair of antennae as oars. The legs are all the time moving, partly because they have gills on them, partly to kick food forward to the mouth. The food is microscopic plants. Under the

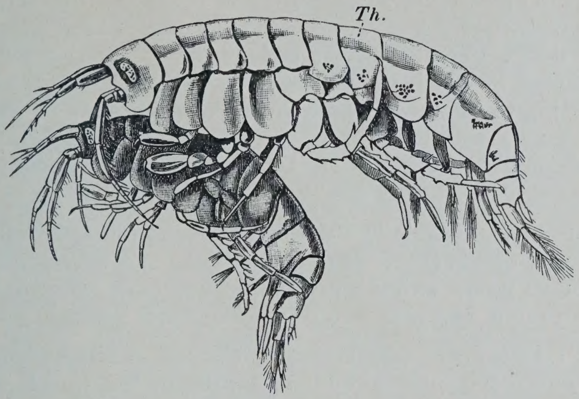

Fig. 113. *Freshwater shrimps.* The drawing shows a male holding a female. *Th.* last segment of thorax.

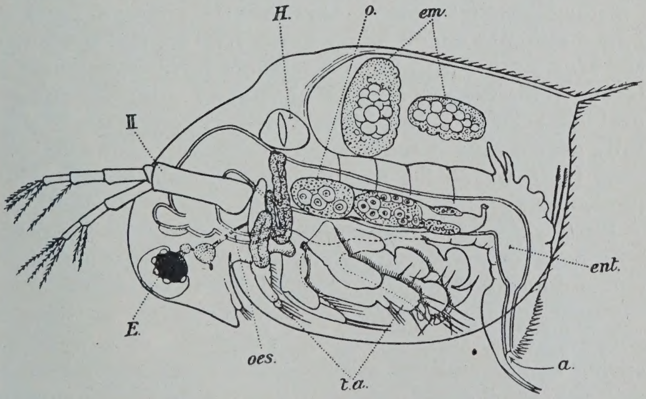

Fig. 114. *Daphnia. E.* eye; *em.* young in space between body and carapace; *ent.* intestine leading to anus (*a.*); *H.* heart; *II*, second antennae; *o.* ovary; *oes.* gullet leading from mouth to stomach; *t.a.* legs.

microscope you can easily see the heart beating through the transparent body, and blood corpuscles moving round the body. Females have a space over the back under the carapace in which the young grow to a certain size before starting to swim. *Daphnia* swim towards or away from a light according to circumstances (Exp. 11). Contrast the behaviour of fly larvae (p. 140) which always crawl away from light.

CYCLOPS. This is another very common little crustacean in ponds (Exp. 12). It has only one eye, hence its name. *Cyclops* swims with its first antennae. Females are often found carrying two bags of eggs.

PLANKTON. A relation of *Cyclops* called *Calanus* is probably the most abundant animal in the world, if we don't count the protozoa. It lives in the surface waters of the sea. These waters contain a vast population of small animals and microscopic plants to which the name of plankton is given (Fig. 115). Very many of the animals are crustaceans like *Calanus*, others are the young or *larvae* of larger animals which when adult live on the bottom of the sea. Crabs, prawns and lobsters have free-swimming larvae in the plankton. So do oysters, marine worms, sea-urchins, starfishes and many others. These animals when fully grown cannot move about much, but currents transport their larvae far and wide. Plankton may produce light, making the surface of the sea glow (cf. p. 4).

Plankton is of immense importance as the food of fishes. The plankton animals feed on microscopic one-celled plants called *diatoms*. Now, for these plants to grow sunlight is necessary. Consequently in winter very few of them are present in the surface waters of the sea. But when the spring comes and the sunshine is stronger they increase vastly in numbers. Using the dissolved carbon dioxide and nitrates in the water, they carry on their photosynthesis and feed. After these microscopic plants have multiplied in the plankton during the spring, the small animals of the

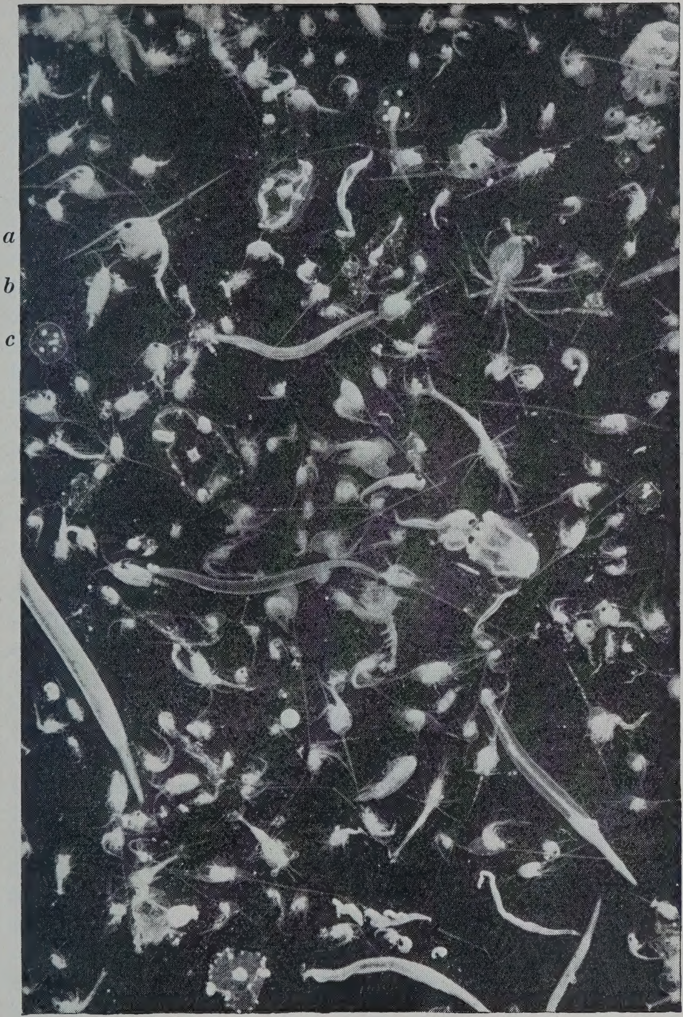

Fig. 115. *Plankton*. This photograph taken under the microscope of plankton from the English Channel shows crab larvae (*a*), *Calanus* (*b*), small jelly-fish (*c*), and other animals. (D. P. Wilson.)

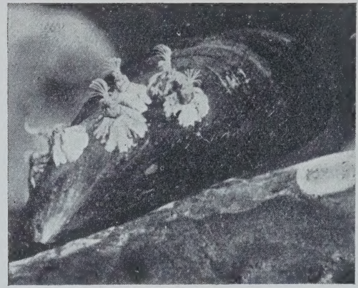

Fig. 116. *Barnacles.* The photograph shows living barnacles on the shell of a marine mussel. The appendages which form a food-catching net are seen. They make rhythmic sweeping movements, catching microscopic plants.

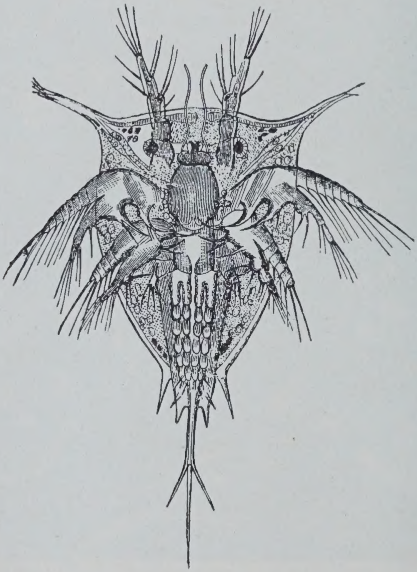

Fig. 117. *Larva of barnacle,* magnified. It is just visible to the naked eye.

plankton begin to increase, feeding on them. This crop of crustaceans and larvae is the rich food of fishes. Thus you see how fish food depends in the end on the sun.

BARNACLES. The barnacle (Fig. 116) does not look in the least like a crustacean. It has not the shape of one and it is permanently stuck to the ground. Nevertheless it is a crustacean. This fact is betrayed by its larva, which is a member of the plankton. The larva (Fig. 117) is very like a young *Cyclops*. After a time it attaches itself to a rock and grows into an animal which looks totally different. The change is greater even than that from caterpillar to butterfly or tadpole to frog. All that reminds you of a crustacean in the adult is the legs, turned into food catchers. Long ago barnacles were believed to turn into geese, because their appendages look a little like feathers!

## V. MOLLUSCS

Another very important phylum is that of the molluscs. A number of familiar animals are in this phylum. The molluscs are divided into three classes. Examples of each of these three are the snail, the oyster and the octopus. These animals look unlike enough to one another, but if you had time to study their anatomy you would find that they are built on the same plan.

The *snail*, like its near relation the *whelk* which lives in the sea, has a spiral shell into which it can retire for protection. Fig. 118 shows a snail creeping along (Exp. 13) on its flattened "foot". At the head end are the mouth and two pairs of tentacles. The eyes are at the ends of the longer tentacles. On the right side is the opening into the lung.

The *mussel*, and its relative the *oyster*, have a hinged shell made of two pieces and closed by two strong muscles (Figs. 116, 119). Oysters and mussels feed on microscopic plants and animals in the water. The organs for catching the food are called the gills because they also serve the purpose of exchanging oxygen and carbon dioxide between water and the blood. Snails, mussels and the octopus all have the blue protein which contains copper in their blood in place of our haemoglobin. We met this already in the crayfish. For catching food the gills are covered with cilia (Fig. 19). The food is entangled in a sticky stuff (mucus) on the gills and the cilia move this to the mouth (Exp. 14). *Pearls* are

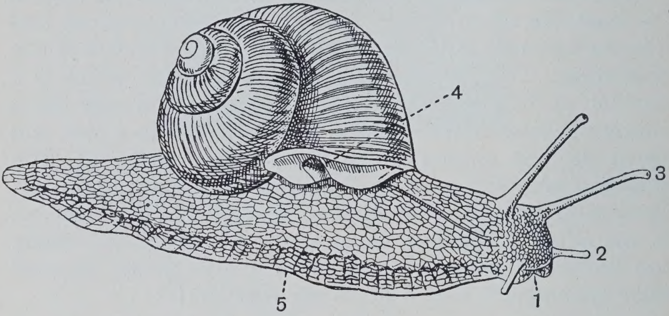

Fig. 118. *Snail.* 1, mouth; 2, front tentacles; 3, tentacles with eyes; 4, entrance to lung; 5, foot.

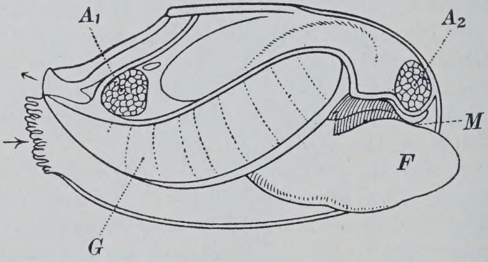

Fig. 119. *Freshwater mussel.* The shell has been removed. $A_1$, $A_2$, muscles which close the shell; *F*, foot; *G*, gills; *M*, mouth. The arrows show the places where the water current containing food enters and leaves the space between the shells.

formed by these animals. You know the "mother-of-pearl" which lines the shells. If a small grain of sand accidentally gets into the living tissues, the latter lay down layer upon layer of mother-of-pearl around it. This makes a pearl. The valuable pearls are found in a kind of oyster living in warm seas.

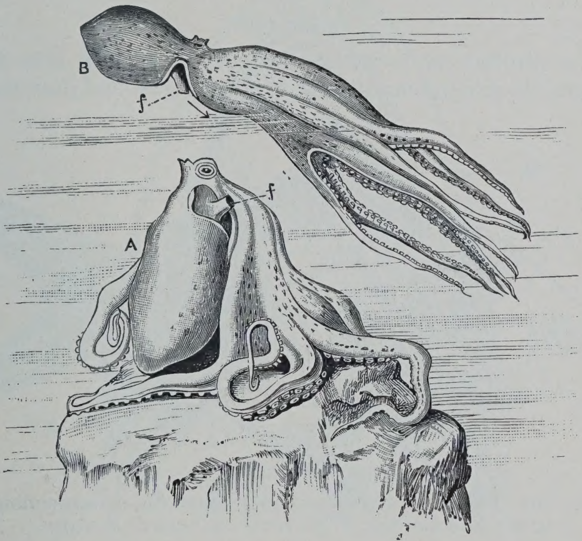

Fig. 120. *Octopus.* A, at rest; B, swimming towards the left by squirting water out of the tube (*f*) in the direction of the arrow. The suckers on the arms, and one of the two eyes, can be seen.

The *octopus* (Fig. 120) lives in the sea on our coasts. Its "foot", instead of being flat like that of a snail, is divided into eight arms. These arms have powerful suckers on them. The mouth is at the base of the arms. An octopus catches crabs with its suckers and the arms convey the prey to the mouth where it is chewed up by strong jaws. The gills are concealed in a cavity which opens by a tube. An octopus can swim rapidly with arms trailing behind it by squirting water out of this tube. Otherwise it creeps along the bottom on its arms. The octopus changes colour with extraordinary rapidity. In a second it has changed from one colour to another. This may be watched in the aquarium at the London Zoo.

## VI. FISHES

The phylum of *vertebrate animals* is divided into five classes, the *fishes*, *amphibians*, *reptiles*, *birds*, and *mammals*.

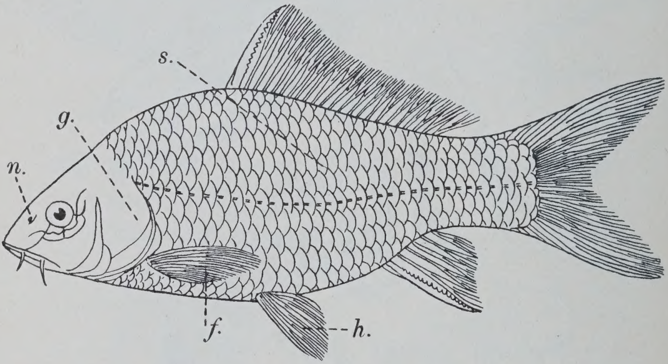

Fig. 121. *Roach.* *f.*, *h.* fore and hind paired fin, corresponding to our arm and leg; *g.* gill cover; *n.* nostril; *s.* scales.

Frogs and newts are amphibians. We need say no more of them. But we must speak shortly of examples of the remaining classes, beginning with the fishes.

As typical examples of *fishes* we may take the herring, the trout or the roach. These animals are clearly adapted for life in water. The body is *stream-lined* (Fig. 121 and Exp. 15). There is an internal *air bladder* for decreasing the specific gravity. There are *fins* for swimming. These include two pairs of side fins which are really the fore- and hind-limbs.

GILLS. Fishes have gills instead of lungs, so that dissolved oxygen can be taken in from the water into the blood and carbon dioxide passed out in solution into the water. The gills are protected on each side of the body by a *gill cover* (Fig. 122). Like the rest of the body this has *scales* on it. If a gill cover is lifted up the gills are seen, coloured red by the haemoglobin of the blood within them. The gills are outgrowths from narrow partitions between five slits. The partitions are called *gill arches*. The *gill slits* between the arches open from the mouth cavity to the space under the gill cover. When a fish opens its mouth to

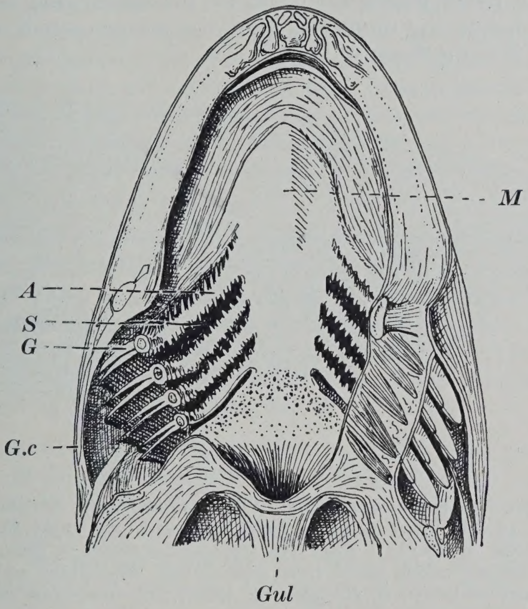

Fig. 122. *Mouth and gills of fish.* *A*, gill arch; *G*, gill; *G.c*, gill cover; *Gul*, gullet leading to stomach; *M*, mouth cavity; *S*, gill slit.

breathe, water enters the mouth. At the same time the flexible edges of the gill covers shut down so that no water comes in that way. Then the mouth cavity is narrowed and so water is driven through the gill slits over the gills. Here the gas exchange takes place. As the water is forced out, the gill cover edges open and at the same time a valve closes inside the mouth so that the water cannot return where it came from.

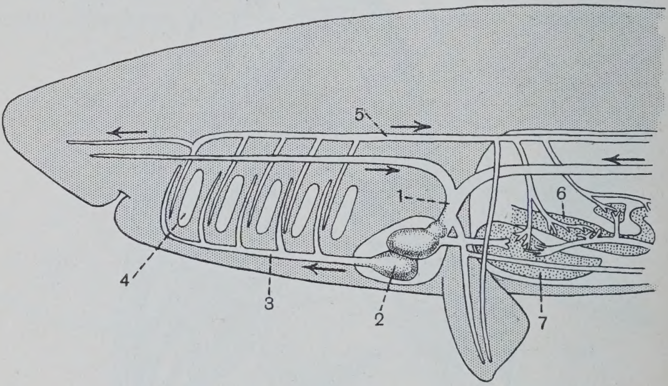

Fig. 123. *Blood system of a fish.* The front end only of the fish is shown. 1, vein bringing blood from head and from body to heart; 2, ventricle of heart; 3, artery taking blood forward to gills; 4, gill slit; 5, artery taking blood from gills to fins, alimentary canal and back part of body; 6, stomach; 7, liver. The directions of blood flow are shown by arrows. Capillaries are omitted.

It is curious that a fish should suffocate out of water, since air contains more oxygen than that which is dissolved in water. The reason is that when out of water the separate gills stick together. Consequently their surface is greatly reduced and enough oxygen cannot get into the blood.

**Blood circulation.** The blood flow to and from the gills is not the same as that through our lungs. You will remember that our heart is a double pump. The right side of the heart sends blood from the body to the lungs. The blood comes back from the lungs to the left side and is then sent to the body. The fish's *heart* is a single not a double pump (Fig. 123 and Exp. 16). It has a single auricle behind and a single ventricle in front. Blood from the body enters the heart and is pumped to the gills. The artery going forward from the ventricle of the heart divides, branches going upwards to each gill arch. There each branch artery splits up into capillaries in the gills. These capillaries join together again, leading into other arteries above the gills. These conduct the blood upward into a big artery that supplies blood charged with oxygen to the whole body.

SEGMENTATION. All vertebrate animals are segmented. The fish, like the frog, shows this by its vertebrae, its nerves and its two pairs of limbs. In addition, the gill arches are clearly repeated in series as segments and so are the arteries to the gills. Further, if the scales are removed from the outside it can be seen that the body muscles are arranged as V-shaped segments.

FLAT-FISHES. Plaice, soles and turbot are peculiar fishes. If you look closely at one of them (Exp. 17) you will see that it is lying and swimming permanently on one side. The gill openings are one on the upper, one on the lower surface. The mouth is placed as it would be if the fish were swimming like other fishes, but the skull is twisted so that both eyes are on the upper side. Flat-fishes start life swimming as other fishes do, but later on as they grow they come to lie on one side while gradually the skull twists (Fig. 124). Then the upper side of the fish becomes coloured, the lower side white.

COLOUR CHANGE. Some fishes change colour according to the background they are on (Exp. 18). Like frogs and prawns, the fishes have branched colour cells in the skin (Exp. 19). The colour change is due to these cells

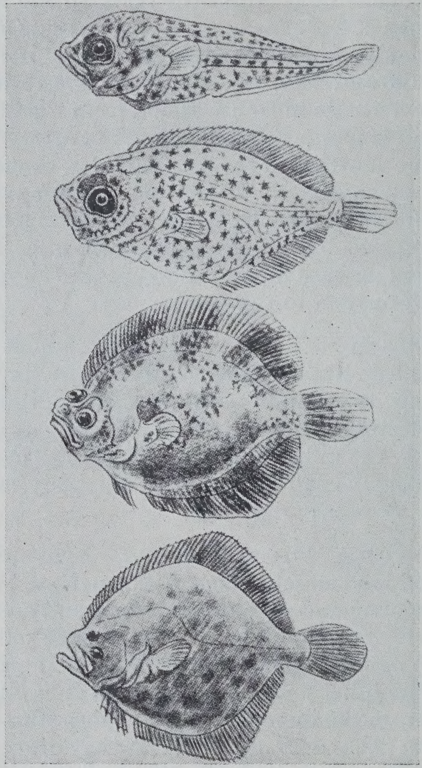

Fig. 124. *Development of flat-fish.* The youngest stage, on top, looks and swims like an ordinary fish. Later on it swims on one side and the eyes twist round so that both are on top. (The drawings of the young stages are magnified compared with the later ones.)

(cf. pp. 53 and 223). Flat-fishes, such as the plaice, not only change colour but also pattern, matching the ground as far as possible.

BREEDING. When fishes spawn the female lays unfertilized eggs and the male pours out sperm on to them. The breeding habits of many fishes are remarkable. Male trout make a sort of nest in gravel of the stream bed, scooping out a hollow with their tail. A female lays eggs in this hollow, the male fertilizes them and then keeps guard over the eggs until the young hatch out, driving away all intruders. Sticklebacks make a more elaborate nest. The male does this work, using weeds for building. Salmon live in the sea but come up rivers to breed. The eel, however, is the most remarkable of all. Eels living in the streams of all countries of Europe go down to the sea to breed. But they do not breed on the coast: they migrate to the depths of the Atlantic near the West Indies. Having spawned there, they never come back. The young eels return to the European rivers in the plankton of the ocean, taking three years to do the journey.

## VII. REPTILES

This is a class of vertebrate animals which contains *lizards* (including the chameleon, Fig. 8), *snakes*, *crocodiles* and *tortoises*. They have no larval stage like the tadpoles of amphibians. The skin is covered by horny scales in lizards and snakes, by an armour in crocodiles and tortoises. Most reptiles hatch out of hard-shelled eggs. Many snakes possess poison glands in the mouth. These are really salivary glands doing an unusual job.

## VIII. MAMMALS

Man is a mammal and so are horses and cattle, elephants, dogs and rabbits. The name mammal is given to the class because the females produce milk to feed their young. The young develop up to a certain stage inside the body of the mother, where they are supplied with food and oxygen from the mother's blood. The most obvious difference between mammals and the other classes of vertebrates is that they have hair on the body.

THE SKIN. Fig. 125 shows you a section through human skin. The outer part of the skin is made of *dead* and hardened *cells*. Below this are *living cells*. The inner living cells go on and on dividing and so new cells get pushed out towards the surface. As they near the surface they die. The outermost layers of dead cells are continually being rubbed off.[1] Amphibians have skins made of living cells

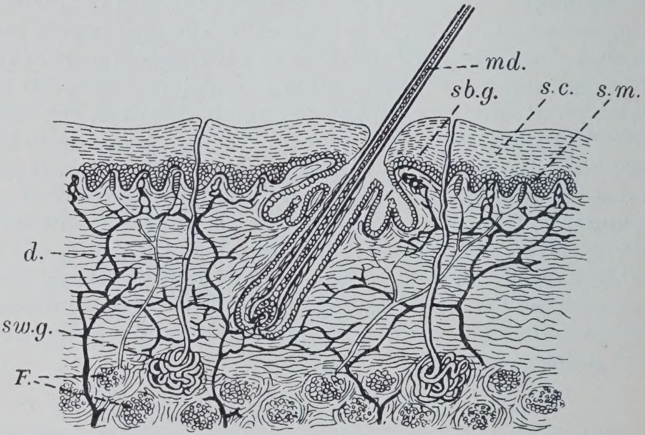

Fig. 125. *Section through human skin.* *s.c.* is the dead layer of cells, with living cells (*s.m.*) beneath it. *md.* is a hair, with two sebaceous glands (*sbg.*). A sweat gland is seen at *swg.*, with its duct (*d.*) leading to the surface. *F.* are groups of fat cells. Blood capillaries (black) and nerves (white) are also seen. Some of the nerves end beneath the layer *s.m.* in cells which are stimulated by touch and by temperature changes.

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[1] The popular idea that we have a number of skins is, of course, quite wrong.

right up to the surface. Consequently they can breathe through the skin, but they require to live in a moist atmosphere. Mammals and reptiles can live in dry air. This kills the outer cells, and the dead cells prevent water loss by evaporation from the body.

Each *hair* is formed by cells at the bottom of a deep narrow pit in the skin. Small glands, called the *sebaceous glands*, open at the base of the hair. They secrete grease. There is a small muscle attached to the bottom of the hair pit. The contraction of these muscles raises the hairs of a cat, but our own hair can hardly "stand on end".

There are numerous *sweat glands* opening on the surface of the skin. A sweat gland secretes sweat from blood brought to it in capillaries.

In the figure you will notice other *capillaries* in the deep layers of the skin. When these widen more blood comes to the skin. In the face this leads to blushing. When these blood vessels narrow the skin blanches. Finally, the endings of *nerves* reach the inner layers of the skin. Touch, temperature and pain stimuli are sent through these nerves to the brain.

MILK GLANDS. Female mammals have specially large sebaceous glands on certain parts of the body. A number of these glands open together to the surface at a nipple. They secrete milk. Milk is white because it is an emulsion of fat (oil) globules in water. In addition, proteins, sugars, salts and vitamines are in solution in the water. Thus all the necessary food substances for the young animal are contained in milk.

BODY TEMPERATURE. Mammals and birds are popularly called "warm-blooded" and other animals "cold-blooded". These terms are not accurate. The truth is that mammals and birds regulate their body temperature so that in health it only varies about a degree above or below a constant value. In ourselves this is 37° C. Other animals have no such control. Their temperature varies with that of the outside world. A better description is to say that birds and mammals are *constant,* the remainder *inconstant temperature* animals.

The *advantages* to an animal of a constant temperature are great. The various chemical processes going on continuously in the living body proceed, like all chemical reactions, more rapidly at a high temperature, slower at a low temperature. And they depend on enzymes. Enzymes work best at a definite temperature (p. 7), which, in man, is near the temperature of the body. Consequently the chemical reactions of life go on in mammals and birds at a rapid and constant rate which is the same in cold and in hot weather. In animals like reptiles or frogs with no temperature control the processes of life go on slowly in winter, fast in summer. Witness the liveliness of a lizard in the heat of the sun and its sluggishness in the cold. But mammals and birds are lively in winter and they are able to populate the Arctic regions.

How is this *temperature control* worked? Heat energy is freed in the living cells, chiefly in the muscles (p. 13). The heat is distributed all over the body by the blood stream. If, now, a low outside temperature begins to cool down the body, more heat is liberated in the tissues. To supply this energy we eat more in winter. If the cooling of the body is excessive we shiver and so produce even more heat. At the same time heat loss from the skin is automatically lessened by the blood vessels to the skin becoming narrower. The hair of mammals helps to lessen heat loss, and so too does fat underneath the skin. A seal has the same body temperature as ourselves, but it can lie for hours on ice without melting it, owing to the fat beneath its skin.

Suppose, now, that the outside temperature rises above that of the body. How is the body temperature kept down to its right value? This is done partly by the blood vessels in the skin becoming wider. Then more heat is radiated from the blood. And also the sweat glands secrete. Sweat consists chiefly of water. Heat is absorbed in evaporation, and consequently as the sweat evaporates the body heat is diminished. Dogs have few sweat glands, but they lose heat by evaporation of water from the mouth. To aid this they pant in hot weather.

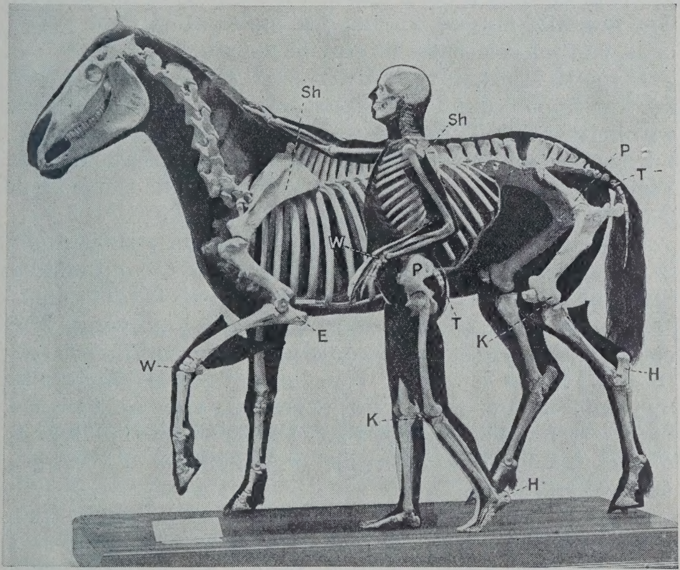

Fig. 126. *Skeletons of horse and man.* ***E***, elbow; ***H***, heel (hock of horse); ***K***, knee; ***P***, hip girdle; ***Sh***, shoulder blade; ***T***, tail; ***W***, wrist ("knee" of horse).

SKELETON. The skeleton of all mammals is built upon the plan of the human skeleton which you have already studied. It differs, of course, according to the particular group of mammals to which each animal belongs. The differences are connected with different modes of life. As an example we will take the horse.

Fig. 126 shows the skeletons of *horse* and man together.

Apart from the upright backbone of man, the chief differences are in the head and limbs. The horse's skull is long, having front teeth for tearing up grass and a long row of back teeth for grinding it. The limbs are specialized for rapid movement over dry plains. They are long and the joints allow only a back and forward swinging movement. The powerful muscles moving the limbs are at their upper ends, so that the centre of gravity is high.

If you look now at the limb skeleton of the horse you will see that humerus and femur are enclosed by the leg muscles within the body. The elbow is just below the breast and the knee is just below the abdomen. What a horseman calls the "knee" of the foreleg is really the wrist, while the hock is the heel bone at the ankle joint.

Instead of having five digits, the horse has a single digit in each limb (Fig. 147, C). This corresponds to our middle finger or toe. The hoof is an enormous nail on this digit. Below the wrist or ankle bones of each limb comes the cannon bone. This is the middle metacarpal or metatarsal (p. 32). Below it are the bones of the middle finger and toe. And, finally, on each side of the cannon bone there is a narrow splint. These splint bones are the second and fourth metacarpals and metatarsals, here reduced to vestiges which do no work.

TEETH. The teeth of mammals vary in number and shape with the work they have to do. All have the same structure: hard *enamel* overlying a bony substance called *dentine*, and a centre of living cells with blood capillaries and nerves. The teeth of mammals can be divided into several kinds according to their position in the jaws and their functions. The dog serves as a good example.

The *dog* has forty-two teeth which are of four different kinds (Fig. 127 and Exp. 20). On each side of the upper jaw there are three *incisors* in front. These are cutting teeth. Behind the three incisors is a *canine* or eye tooth. It is for killing prey, for grasping, and for attack and defence.

Then there follow four *premolars* with cutting edges and two *molars* for breaking up the food. The teeth of the lower jaw are similar except that there are three molars instead of two on each side. The first lower molar has a cutting edge working against the last upper premolar.

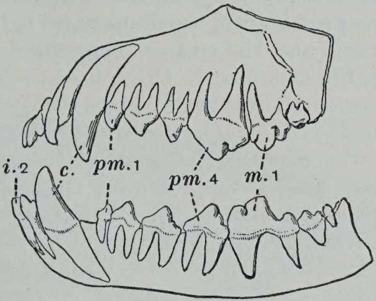

Fig. 127. *Teeth of dog*. The roots of the teeth are seen in the jaws. *c*. canines; *i*.2, second incisor; *m*.1, first molars; *pm*.1, first premolars; *pm*.4, fourth premolars.

A mammal has two sets of teeth during its lifetime. It is born with so-called *milk teeth*. These are later on pushed out by the permanent teeth. The permanent molars, however, have no corresponding milk teeth.

In *man*, on each side of each jaw there are two incisors, one canine which is very like the incisors, two premolars and three molars.

The *rabbit* (Exp. 20) has two pairs of incisors in the upper jaw for tearing grass, the front pair being much the larger. In the lower jaw there is one pair. Unlike our teeth and those of the dog, the incisors of the rabbit continue to grow as they are worn down. Canines are absent and there is a long gap before the premolars (three pairs in upper, two pairs in lower jaw) and molars (three pairs of each in each jaw). These all have broad ridged tops for crushing and grinding.

BREATHING. The body cavity of a mammal is divided into a front part and a back part. The dividing wall is a sheet of muscle called the *diaphragm* (Fig. 3). In front of the diaphragm are heart and lungs. Behind it are liver, stomach, intestines and other organs in the body cavity. The part of the body between neck and diaphragm is called the *thorax*. The part behind the diaphragm is the *abdomen*.

The diaphragm and the *ribs* are concerned in breathing. Ribs are movably attached to the spine at one end and to the breast bone at the other. Muscles connect the ribs to one another and to the vertebrae. When we breathe in, these muscles raise the ribs. If you look at the picture of the human skeleton (Fig. 12) you will see that when the front ends of the ribs and the breast bone are raised up, the cavity of the thorax must become bigger. For as each rib moves upwards its place is taken by a rib with a wider arch.

The diaphragm is like a basin upside down. It is concave towards the abdomen. As we breathe in, not only do the ribs move up but the muscles of the diaphragm contract. This lessens the concavity of the diaphragm. The result is again that the cavity of the thorax increases in size. The result of this increase in the size of the thorax is that air rushes into the lungs.

The movement of breathing out is more passive. Ribs and diaphragm return to their former positions and so air is expelled from the lungs. This is aided by the lungs themselves which are elastic.

WHALES. Porpoises, dolphins and whales belong to a group of mammals which pass all their lives in the sea. Although they must come to the surface from time to time to breathe air, their bodily structure is as completely suited to water life as that of fishes. When a whale is coming up to take a fresh breath, it blows out air through its nostril before it reaches the surface. This results in spouting. A column of hot moist air rises and the moisture quickly condenses, forming the spout. Whales are hairless. A thick layer of fat called blubber preserves the heat of the body. The largest whale is 100 feet long. Whales are the most bulky animals that have ever existed on the earth.

The fore-limbs of whales have the form of fins, although their skeleton has humerus, radius and ulna as in other mammals (Fig. 128). But from the outside there is no sign of hind-limbs. Nevertheless useless traces of hind-limb skeleton exist inside the body.

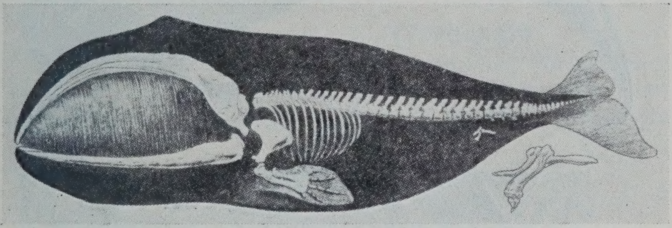

Fig. 128. *Skeleton and outline of a whalebone whale.* The whalebone filter is seen occupying the space between the very long jaws. The bones of the fore limb can clearly be made out. The useless traces of hind limb skeleton can also be seen. They are drawn enlarged below.

There are two groups of whales. The first have teeth, the second have none. Instead, they have large numbers of flat horny rods made of "whalebone" in the mouth. The rods with frayed edges make a strainer.[1] Although of immense size themselves, these whales feed on the minute animals in the plankton. They obtain their food by taking in mouthfuls of water and straining it out through the whalebone filter.

BATS. Just as whales are specialized for swimming, so bats are mammals adapted to flying. The arm is a wing. The fingers are very long and a membrane of skin is stretched between the fingers and the side of the body

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[1] This can be seen in the Natural History Museum in London.

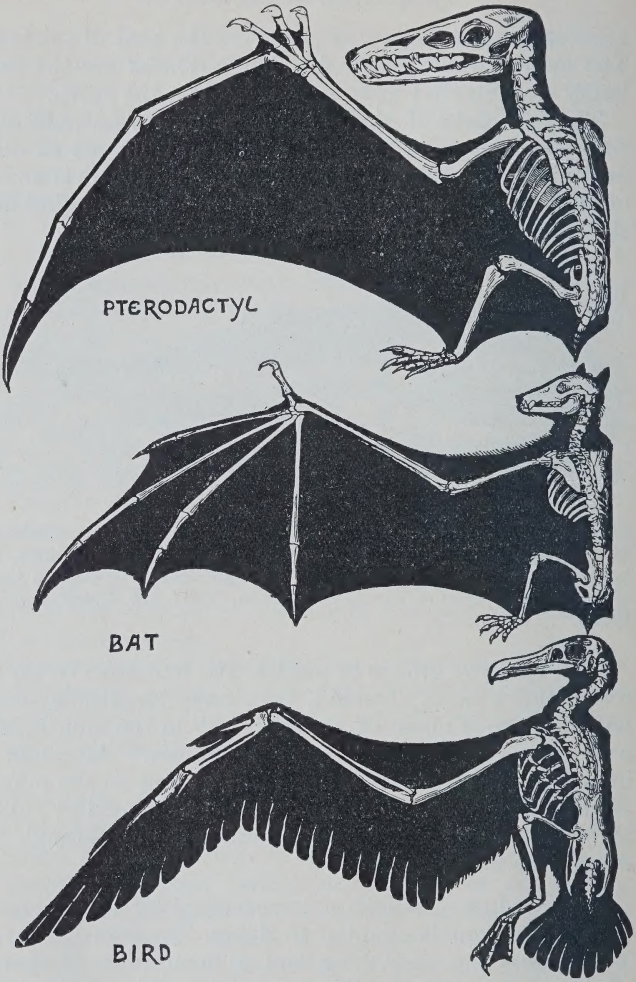

Fig. 129. *Wings.* The bat's wing is a skin membrane supported by arm, second to fifth fingers, and leg. The feathers of the bird's wing are on the arm and enlarged second finger. The pterodactyl's wing (p. 295) was a skin membrane supported by arm, fourth finger, and leg.

(Fig. 129). The thumb alone is not included in the wing membrane and ends in a hook-like nail. Bats have very poor sight but the skin on the face is extremely sensitive to faint air currents. With the help of this sense bats can avoid obstacles even when flying in darkness.

## IX. BIRDS

The structure of birds is specialized in numerous ways to enable them to fly.

FEATHERS, like the hairs of mammals, are produced (secreted) by cells in the skin, but they are much more complicated than hairs. Each of the large feathers has a central *quill*. On either side of the quill there are *barbs*, each of which has numerous branches called *barbules* (Fig. 130). The barbules on the sides of the barbs towards the tip of the feather have *hooks* on them. These hook on to the barbules of the next barbs (Exp. 21).

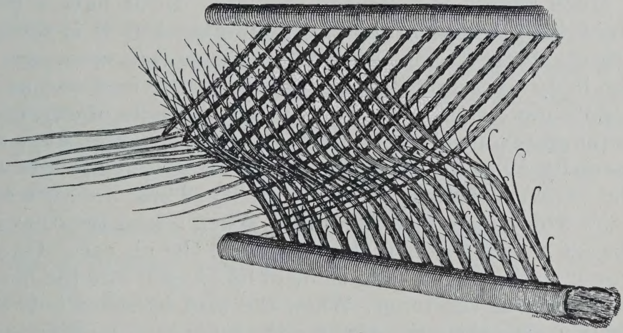

Fig. 130. *Part of feather magnified.* Two pieces of barbs have been cut off the feather. The barbules with their hooks are seen. This drawing was made by Robert Hooke in 1665.

THE WING. The feathers on the wings are used for flight. The wing, of course, is the fore-limb, corresponding to our arm. Fig. 129 shows that the wing skeleton consists of *humerus, radius, ulna, wrist* and *hand* bones. But the hand has only three fingers, and, of these three, one is much bigger than the others. This one corresponds to our *index finger*. The largest feathers for flight are outgrowths from the skin over the ulna, hand and index finger (Exp. 22). Fig. 129 makes it obvious that the wings of birds and of bats are constructed in quite different ways.

ENERGY SUPPLY. To move the wings powerful muscles are required. These are the "breast" of a bird. The breast bone has a keel on it for the attachment of flight muscles.

Much energy is expended in flight. Birds have a constant body temperature like mammals, but it is several degrees higher. This enables the chemical processes in the body to go on at a greater rate in the bird and so to supply more energy. For this a larger supply of oxygen is required. To meet the demands for oxygen, the lungs are specially efficient. There are great *air sacs* lying between the various organs in the body cavity. These are air reservoirs which open into the lungs. When a bird breathes in, the air rushes through the lungs into the air sacs. On its way inwards the air loses some of its oxygen into the blood capillaries of the lungs. When the bird breathes out, the air sacs are partly emptied *via* the lungs, and more oxygen is then absorbed into the blood. Thus the efficiency of the lungs is doubled.

## PRACTICAL WORK

*Exp.* 1. Examine the external features of a crayfish, including the gill chamber.

*Exp.* 2. Show how the muscles are attached in the limb of a lobster or crab.

*Exp.* 3. Examine mandible, second maxilla and third foot-jaw.

*Exp.* 4. Attach a crayfish on its back by rubber bands to a piece of wood weighted with lead, and put it under water. The movements of foot-jaws and baler can then easily be watched.

*Exp.* 5. Demonstration of dissection to show heart and arteries. The stomach should be opened to show the gastric mill.

*Exp.* 6. Demonstration of dissection of nervous system.

*Exp.* 7. Put crayfishes in two glass-bottomed vessels containing water. Lay the vessels one on black paper, the other on white paper in a bright diffuse light for an hour. Then remove the vessel which was on a black background on to white paper and compare the colours of the animals in the two dishes.

*Exp.* 8. Examine a crab and lift up its abdomen.

*Exp.* 9. Examine a freshwater shrimp with a lens.

*Exp.* 10. Examine *Daphnia* under the microscope in a compressorium. Notice movements of antennae and limbs. Watch the heart beating. You can stop the heart and start it again. *Daphnia* is held in a compressorium and the water sucked out with blotting paper. More water charged with carbon dioxide by blowing through it is let in under the cover slip with a pipette. The heart stops in a few seconds. Then replace this water by ordinary water. The heart beats again. You can show that the rate of heart beat changes with temperature by immersing the compressorium in a flat glass dish containing warm or cold water on the stage of the microscope. Watch also the movements of eye and gut. Look for young in brood pouch.

*Exp.* 11. *Daphnia* swim towards light. Put the glass vessel containing the animals in darkness for an hour. When exposed to light they now swim away from it.

*Exp.* 12. Examine *Cyclops* under the microscope.

*Exp.* 13. Study a snail creeping up a glass surface. Waves can be seen passing forwards over the surface of the foot. Look for the mouth, eyes and lung opening. It can be shown that the tentacles can smell by bringing a glass rod dipped in alcohol or xylol near to them.

*Exp.* 14. Examine a mussel with one valve of the shell removed and the mantle cut away. Study the movement of mucus caused by the cilia by dropping starch grains stained with iodine on to the surface of the gill. If mussels are put into water containing dilute Indian ink their gills will have filtered off all the ink by next morning.

*Exp.* 15. Examine the external features of a fish. Lift up the gill covers to see the gills. Slit open the pharynx to see its connection with the gills.

*Exp.* 16. A dissection of a fish to show heart, gill arteries and swim bladder should be shown to the class.

*Exp.* 17. Examine a flat-fish, noting shape of mouth, position of eyes and gills, coloration.

*Exp.* 18. Put minnows or sticklebacks in glass-bottomed vessels such as accumulator jars for an hour on black and on white paper to see their colour changes.

*Exp.* 19. Examine scales of herring or other fish under the microscope mounted in glycerine to see the colour cells.

*Exp.* 20. Examine the skull of dog or rabbit to see teeth.

*Exp.* 21. Study the structure of a feather under the microscope.

*Exp.* 22. Examine a wing to see bones and attachment of feathers.

## *CHAPTER XVI*

# GROWTH AND DEATH

FERTILIZATION. The life of an individual animal starts by an egg uniting with a spermatozoon. This is the fertilization of the egg. Eggs, as you know, are produced by the ovaries. Each egg is a single cell, whether it be as large as the egg of an ostrich or as small as that of a mammal. An egg of a mammal measures only 0·2 millimetre across, which means that it is about the size of a full stop. Spermatozoa are produced in the testes. Each spermatozoon, too, is a single cell (Fig. 49).

When animals live in *water*, their unfertilized eggs and spermatozoa are frequently both shed into the water. There the spermatozoa swim to the eggs. This happens with marine worms, with sea-urchins and star fishes, with oysters, with fishes and frogs. Compare also *Hydra* (p. 114). But in the case of *land* animals, insects, reptiles, birds and mammals for instance, this would not work. So male and female individuals unite in order that spermatozoa may reach the eggs inside the body of the female.

Spermatozoa are always much more numerous than eggs. Fig. 50 shows spermatozoa surrounding an egg. One spermatozoon is uniting with the egg. The nucleus of the spermatozoon then fuses with the nucleus of the egg. This is the act of fertilization. After this the fertilized egg divides into two cells. Each of these then divides again, and so successively 4, 8, 16, ... cells are formed (Fig. 51). At first all the cells are alike. When the cells have become more numerous by these divisions, they become different from one another, and so the various tissues and organs of the young animal are formed.

FATHERLESS OFFSPRING. It has been found possible in the laboratory to make some eggs divide and grow into adult animals without the egg being fertilized by a spermatozoon at all. This is done by putting the eggs into certain chemical solutions. The egg of the sea-urchin (pp. 116 and 216) has been made to develop in this way. Frogs too have been raised from the egg without their having a father.

This has been done by biologists in the laboratory, but in nature some few animals start life normally from eggs which are unfertilized. For example, *Daphnia* (p. 224) does this all through the summer. All the individuals you catch in a pond in the summer are females. Their eggs develop without fertilization. In the autumn only do males appear and their sperm then fertilizes the eggs of the females.

EMBRYOS AND LARVAE. Some eggs are large and others small. The difference depends on the amount of *yolk* in the egg. The yolk is the food store for the developing young, or *embryo*. When an egg is small, having little yolk in it, the young animal usually *hatches* early and seeks its own food. We call the young *larvae* when they are different in structure from the adults. Many marine animals, such as worms, sea-urchins, crabs and oysters, hatch as larvae. You have seen that these larvae live in the plankton (p. 226). Many insects, too, such as flies, butterflies and bees, have larvae. If, on the other hand, the egg has a lot of yolk, like the bird's egg, the embryo grows quite big before it hatches, and there is no larva. Mammals have very small eggs, but in this case the embryos grow inside the body of the mother. They are fed, not from yolk, but from the blood of the mother until they are born.

THE TADPOLE. Frogs have eggs with some yolk in them but much less than in the hen's egg. Frogs breed in the spring. They go into the water, where a male clasps a female, holding her it may be for some days until she lays eggs. As the eggs are laid he pours out his sperm. Fertilization of the eggs thus takes place in the water.

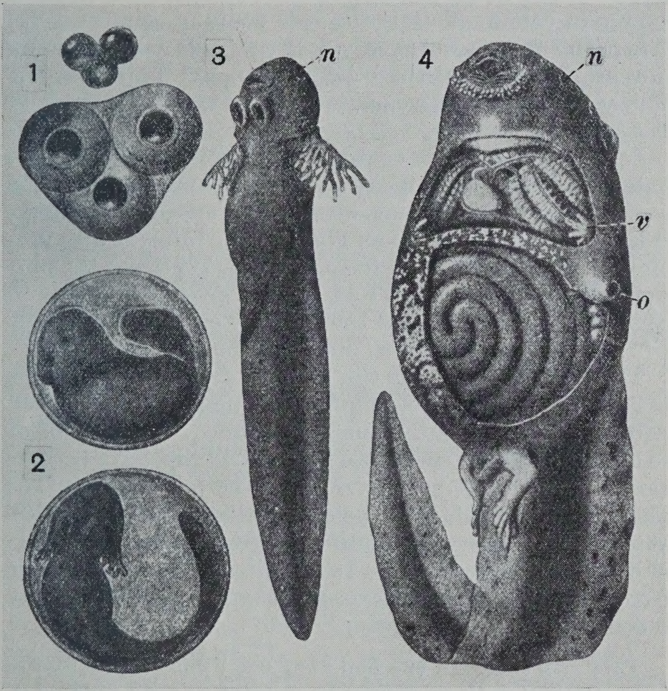

Fig. 131. *The tadpole.* 1, three eggs: above, as they are when still in the body of the female; below, as they are in the water, each surrounded by jelly. 2, tadpoles before hatching out of the eggs. 3, young tadpole with suckers, mouth, nose opening (*n*) and outside gills. 4, older tadpole partly dissected. In 4 the heart, arteries leading to the gills as in a fish, and the gills are seen. In the abdomen is the spiral intestine. *n*, nose opening; *o*, opening from gills; *v*, beginning of front legs. The hind legs are also seen.

The black eggs with their covering of jelly for protection can be found in masses in ponds. One side of the egg is lighter in colour. This is the side containing most yolk. When the fertilized egg divides, the cells on the yolky side are bigger than the others (Exp. 1).[1] Later on, the embryo can be seen developing from the egg inside the jelly (Exp. 2).

Some days after the eggs are laid the larva, or tadpole, hatches. It has three pairs of *gills* sticking out into the water, a *tail* for swimming, *mouth, nose openings* and *anus* (Fig. 131). After a time four *gill clefts* are formed, with gills on their walls as in a fish (compare Fig. 122), and the outside gills wither. Then a fold of skin grows backward to cover the gill clefts so that there is only one opening on the left side for water to come out from the gills (Exp. 3).

The beginnings of legs can next be seen growing at the base of the tail. The fore-limbs start under the gill cover. After about two months lungs are formed. A fortnight or so later the tadpole turns into a frog. Gill slits have become closed. The fore-limbs grow out and the tail shortens. The blood circulation of the tadpole is like that of a fish (Fig. 123). When the tadpole turns into a frog with lungs, its blood circulation changes into that shown in Fig. 15. This change from larva to adult is perhaps not so great as in a butterfly but it is sufficiently surprising.

THE CHICK. In the hen's egg the "yolk" is really the huge egg cell with an immense amount of food yolk in it. The "white" contains a store of water which is gradually taken into the embryo as it develops. Owing to the large quantity of yolk the fertilized egg cannot divide completely into 2, 4, 8, etc. cells like smaller eggs. Cell division takes place at one side only of the yolk and there the embryo is formed (Exp. 4). The growing chick gradually absorbs the yolk into its intestine.

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[1] Compare Fig. 51. There is very little yolk in the egg of the sea-urchin and when it divides the cells are almost equal in size.

MAMMALS. In mammals the fertilized egg develops into the embryo inside the body of the mother. This occurs in an enlargement of the oviducts which is called the *uterus* or *womb* (Exp. 5). The embryo is attached to the wall of the uterus. Here its blood vessels come very close to those of the mother. In this way food and oxygen diffuse from the mother's blood into the blood of the embryo, while carbon dioxide and urea pass the other way. After birth a trace of this former connection remains as the navel.

GROWTH, OLD AGE AND DEATH. As an animal grows from a fertilized egg, its size at first increases more and more rapidly in each successive hour or month. The *rate* of growth goes on increasing. Then after a time growth slows down. The rate of growth becomes less and finally growth stops. After this the adult animal lives for a certain time without change of size, until finally it dies. What are the reasons for these changes in the rate of growth, for old age and death?

TISSUE CULTURE. Of late years it has been found possible to take fragments of living tissue from the body of an animal and keep them alive. Not only do the cells remain alive outside the body but they divide. In other words, the fragments of living tissue grow. This method is called tissue culture. The way it is done is as follows.

First blood is taken from an animal, for example a fowl. The *plasma* (p. 22) of this blood is separated from the corpuscles. Then an embryo chick or mouse is cut up into small pieces in a salt solution. The resulting liquid is called *embryo extract*. Next, a small fragment of living tissue, about a millimetre long, is taken from an animal just killed, usually an embryo. The fragment is placed on a cover-slip. On to it is put a drop of embryo extract and a drop of plasma. The liquid at once clots (p. 24). The cover-slip is then turned upside down over a hollow-ground microscope slide and the edges of the cover-slip are sealed with paraffin wax (Fig. 132). All this is done under very strictly aseptic conditions (p. 85), as in a surgical operation. Otherwise bacteria from the air or instruments would infect the culture and multiply in it.

Very soon cells begin to wander out from the tissue fragment like so many amoebae (Fig. 133). This can be watched under the microscope. The cells that have migrated out from the tissue fragment soon begin to divide again and again. Thus the tissue grows, until after a couple of days the drop of clotted culture fluid is almost filled with cells. Then growth stops because the food substances in the blood plasma are used up, because excretions from the cells have accumulated, and because there is no room for more growth. Next, the experimenter opens the culture, prepares another with fresh plasma and embryo extract, and transfers a fragment of the tissue from the first culture to it. If he does this regularly every second day the tissue will go on and on growing indefinitely.

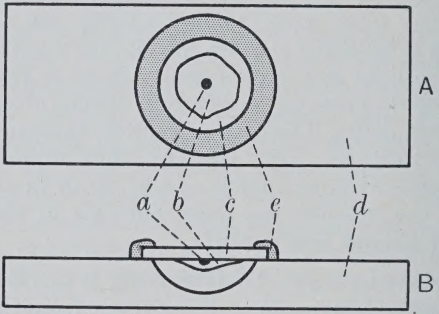

Fig. 132. *Tissue culture preparation.* A, top view; B, side view. *a*, fragment of living tissue; *b*, clotted drop of plasma and embryo extract; *c*, cover slip; *d*, microscope slide with a cavity in the middle; *e*, paraffin wax.

Under the conditions of tissue culture, the cells of fragments of muscle, epithelium, connective tissue and so on move about like amoebae. In the body of the animal from

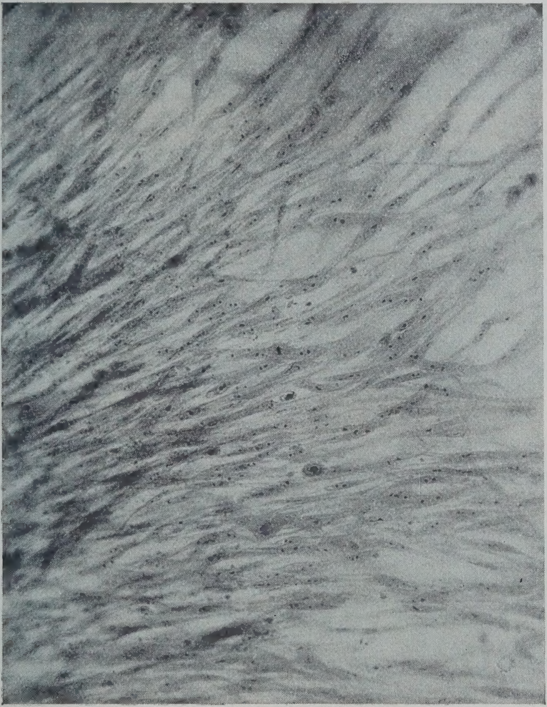

Fig. 133. *Cells living outside the body*. Photograph taken under the microscope of chick cells in tissue culture. The cells are migrating towards the right, like amoebae, from a fragment of living tissue which is outside the picture on the left. Black spots can be seen in the nuclei. (F. G. Spear.)

which these cells were taken they do not normally migrate in this fashion. Almost the only occasion in which cells in

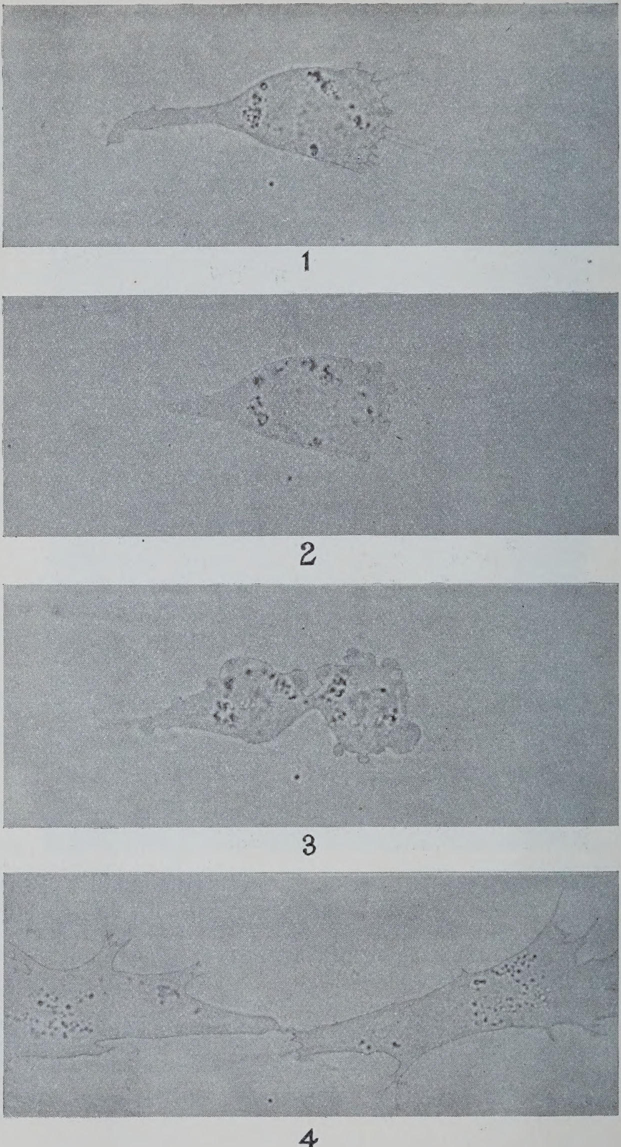

Fig. 134

the body migrate is when they are spreading and dividing to repair a wound.

All the details of *cell division* can be studied under the microscope in tissue cultures. Fig. 134 shows four stages of the division of one cell into two. The cell, which previously had pseudopodia like *Amoeba*, at first becomes round. Then the nucleus divides, and next the whole cell divides. In the later stages of division bubbles of protoplasm appear on the edges of the daughter cells (Fig. 134, 3). Finally the two daughter cells move apart from one another like the daughter cells of a dividing *Amoeba* (Fig. 17). This is in tissue culture, but in the body of a growing animal the daughter cells would be closely packed together by the cells all around them and could not move apart.

THE FIRST STAGE OF GROWTH. This new method of tissue culture has thrown a lot of light on the questions we asked about the growth of animals. In the first place, the cells in tissue culture go on and on dividing at regular intervals, once about every twelve hours. Cell division continues indefinitely at this regular rate unless the culture is allowed to become overcrowded.

The division of cells at fixed time intervals takes place not only in tissue culture but also when a fertilized egg divides into 2, 4, 8, etc. cells (Fig. 51). Likewise it occurs in a culture of bacteria, of *Amoeba* or of *Paramecium*. We conclude, therefore, that a steady rate of division is a general property of cells. From this a consequence immediately follows: namely, that the bulk of protoplasm must be doubled at regular intervals. For each time that protozoa or the cells in tissue culture have divided, they grow to their full size

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Fig. 134. *Division of a cell in tissue culture.* Four photographs from a cinematograph film taken through the microscope, showing a living connective tissue cell of the chick dividing into two cells. In 1 and 2 the nucleus is dividing, in 3 the whole cell is dividing and in 4 the two daughter cells are moving apart with the help of pointed pseudopodia. (R. G. Canti.)

before again dividing. As a result the total mass of protoplasm is doubled at each cell division. In other words, the rate of increase of bulk gets faster and faster. And this was just what we found in the first growth stage of an animal. The rate of growth in bulk increases steadily, up to a point.

WHY GROWTH STOPS. What is the reason, then, that the growth rate of an animal slows down after a time? It is not because the tissues are older. For in tissue culture the cells go on indefinitely dividing steadily at the same rate. And more than this, not only cells from an embryo, but likewise cells from an adult animal which has stopped growing will divide and grow in tissue culture. They have not lost the power of division, although in the body of the adult animal from which they were taken they no longer divide and grow, except when repairing a wound.

Now, for the cells to grow in tissue culture the presence of what we have called embryo extract is essential. There is thus some substance, as yet unknown chemically, contained in the tissues of embryos which is necessary for cells to grow. And as an animal grows, this substance gradually disappears from the body. When it is all gone, cell division stops.

In addition to this there are surely other reasons for the slowing down and final stoppage of the growth of an animal. In order that tissue cultures shall go on, they have to be started afresh each second day. Otherwise growth ceases because food for the cells is exhausted and excretions accumulate. Moreover, the blood of adult animals contains something which actually slows or stops growth of cells. It does this, for instance, when injected with a syringe into the blood stream of a young growing animal. And blood plasma from old animals is not so good for the growth of cells in culture as that from young animals.

CELL IMMORTALITY. In a sense bacteria or *Amoeba* can be said to be "immortal". If they are living in the right conditions of temperature and food they will go on regularly dividing without stop. A culture of *Paramecium* has been kept going for thirteen years. It passed through 10,000 generations. The excess population was of course removed at intervals to prevent overcrowding. And at the end the division rate was just the same as at the beginning. Unless they meet with an accident, then, one-celled organisms are "immortal". They do not age nor finally die.

The cells of higher animals in tissue culture are just the same. Connective tissue cells from a chick have been kept going in tissue culture for twenty-one years. All this long time the cells grew and divided at regular intervals, and up to the end of the experiment there was no slackening of growth rate. Yet twenty-one years is more than twice the length of life of a fowl.

Moreover, there are some cells in our own bodies which may go on living for an indefinite time. All cells in our bodies are of course the direct descendants of cells which existed millions of years back in our ancestry. Yet nearly all of them are doomed to die at our death. But not all of them. There are cells in testis or ovary which need not die. Spermatozoa or eggs may give rise to a long succession of future generations.

Thus we come to the remarkable conclusion that under suitable conditions living cells are "immortal". Yet all cells in the body, except with luck one or two cells in the reproductive organs, will stop dividing as growth ceases, will age and finally will die. Why is this so? It is the price paid for having a complicated body. The cells in the body die: separated from the body in tissue culture the cells need not die. The body is a mortal whole made of immortal parts.

## PRACTICAL WORK

*Exp.* 1. Collect frog spawn from a pond. The first cells formed by division of the egg can be seen under a low power of the microscope if the egg is lighted from the side.

*Exp.* 2. Watch the gradual development of the frog embryo until hatching. Keep the tadpoles until they turn into frogs, studying the changes in structure. Put a large tadpole into dilute Indian ink to see water pumped out through the gill cover opening.

*Exp.* 3. The carbon dioxide output of tadpoles can be demonstrated as follows. Take a glass boiling tube with a bung bored with two holes into which are fitted glass tubes bent at right angles. One glass tube passes $\frac{3}{4}$-way down the boiling tube, the other ends just beneath the bung. Put water in the boiling tube to fill it $\frac{1}{3}$-way up. Add several drops of phenol red (·4% solution). Place several tadpoles in the water. Carbon dioxide given off by the animals will change the indicator from red to yellow. If the water is too acid at first, suck air through it. Similarly when the animals have turned the indicator yellow it can be brought back to red and the experiment then continued.[1]

*Exp.* 4. Take a hen's egg which has been two days under a broody hen and open it to see the developing embryo on one side of the yolk. Open another egg one or two days later to see a more advanced embryo with the heart beating.

*Exp.* 5. A pregnant mouse should be dissected and shown to the class to see the embryos in the uterus.

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[1] This method is equally suitable for other small aquatic animals. It can be made quantitative by setting up buffer standards plus the indicator in other boiling tubes and observing the *p*H change per unit time.

## *CHAPTER XVII*

# INSTINCT AND REASON

AN *Amoeba* reacts to changes in the world outside it. It *reacts* to changes in its environment or *stimuli*. If it is touched it withdraws its pseudopodia and rounds itself up. If it meets food the *Amoeba* swallows it. So, too, more complicated animals than *Amoeba* react to stimuli from their environment. They will move towards food or flee from danger. But such reactions of higher animals are not so simple as in the case of *Amoeba*. For certain definite muscles of the body are set in action or certain glands secrete.

It is obvious therefore that there must be a *means of communication* in the body. There must be communication from the place on the surface affected by the stimulus to the place at which muscles or glands work. Take the case of a man who "jumps" when a pistol is fired. There is communication from the ear to the muscles concerned in "jumping". And more than this. There is a *central command*, deciding which particular muscles shall obey.

The means of communication in the body are both *nerves* and *chemical substances* circulating in the blood. The central command is what is called the *central nervous system*. In vertebrates this is the brain and spinal cord. In insects, crustaceans and the earthworm it is the ganglia of the nerve cord.

NERVES. Nerves, like all other living parts of the body, are made up of cells. *Nerve cells*, however, differ from other cells, such as blood corpuscles or cells of the epithelium lining the frog's intestine, by being extremely long. Fig. 135 shows a nerve cell. The long thin part is called the *nerve fibre*. It has a branched end. The part of the cell containing the nucleus is called the *cell body*. It also

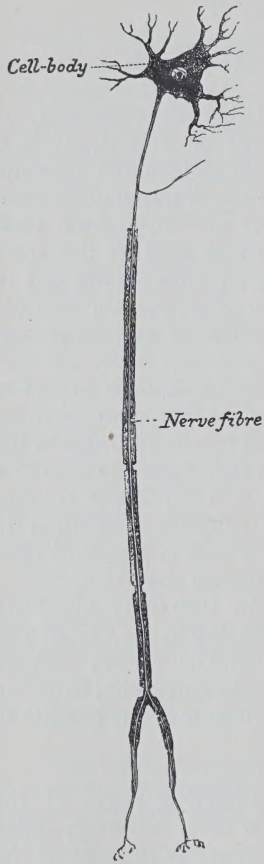
Cell-body
Nerve fibre

Fig. 135. *Nerve cell.*

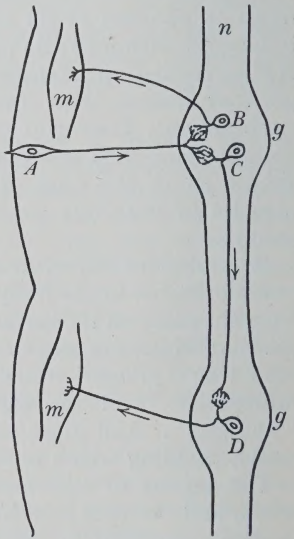

Fig. 136. *Reflex.* Diagram of part of two neighbouring segments of a worm and their ganglia (*g*,) in the nerve cord (*n*). *A*, nerve cell in skin; *B*, and *D*, nerve cells in ganglia, communicating with muscles (*m*); *C*, association nerve cell. The directions of the nerve impulses are shown by arrows.

has branches of protoplasm, coming out opposite the fibre. A nerve such as you have seen in dissection is made up of thousands of nerve fibres.

REFLEXES. Let us see what happens when an animal reacts to a change in its environment, or *stimulus*. Take the simple case of a worm which is touched and in consequence wriggles. There are nerve cells with their cell bodies in the worm's skin (Fig. 136, *A*). When touched, such a cell sends a message, a *nerve impulse,* along its fibre to the ganglion in the nerve cord. Here the end branches of the nerve fibre are in contact with branches of another nerve cell, *B*. The nerve impulse passes into the second nerve cell and along its fibre to a muscle, which then contracts. Actually a number of nerve cells in the skin would be touched, and impulses would be sent inwards along a lot of nerve fibres in a nerve, not along a single one. The movement of the worm which results from the touch stimulus is called a *reflex*.

But when a worm is touched it is not a single muscle that contracts but a number of muscles in several segments of the worm. How is the nerve impulse communicated to these other muscles? The end branches of the incoming nerve cell *A* are not only in contact with branches of the outgoing cell *B*. They are in communication also with other nerve cells such as *C*. This cell *C* has fibres running up and down the nerve cord. It is called an *association nerve cell,* and it distributes the nerve impulse to yet other nerve cells, such as *D*, in the ganglia of neighbouring segments. These outgoing nerve cells *D* send on the impulse to muscles of their own segments.

THE NERVE IMPULSE. We do not actually know what is the nature of the nerve impulse. It is not an electric current, but as it passes along a nerve fibre it is accompanied by a change of electrical potential. This change is very small indeed but in researches made quite lately it has been amplified by an amplifier such as is used in wireless. This has shown that when a nerve impulse passes along a nerve fibre there is not a single change of potential but a very rapid succession of changes. The frequency of these may be 30 per second. The nerve impulse, then, is not to be compared with a stream of water but with a volley of machine gun bullets. The rate at which this rhythmic impulse passes along a nerve varies in different animals. In an arm nerve of man the velocity is 70 metres per second, or 160 miles an hour.

HORMONES. Communication between one part of the body and another is not always by nerves. In some cases it is done by chemical substances circulating in the blood. These are called hormones, or *internal secretions,* because they are secreted by glands *into the blood.* They do not pass outwards to the alimentary canal (digestive enzymes) nor on to the surface of the body (sweat) but go into the blood stream. We already met one example of a hormone which signals to the *pancreas* to secrete trypsin when required (p. 23). *Milk glands* secrete milk at the right time in response to a hormone coming to them from the ovary.

Prawns or crayfishes, when they move from dark on to light-coloured rock or sand, themselves go pale (Fig. 112). This is due to a change in branched *colour cells,* just as in the frog (Fig. 21) and the fish (p. 235). The signal to the colour cells is given by hormones in the blood. Light reflected from the light-coloured ground affects the crustacean's eye. As a result a gland in the eye stalk secretes the hormone into the blood which conveys it to all the colour cells. In response to this signal the pigment granules become grouped together in the centre of each colour cell and the animal looks light-coloured. In the same way the colour cells of frogs make the animals go dark or light in response to hormones in the blood.

Hormones are also concerned in *growth.* There is a gland called the *thyroid* situated beneath the gullet in vertebrates. Its secretion is necessary for the change from tadpole to frog to take place. If the thyroid is removed from a tadpole by an operation, the animal grows bigger than normal but never changes into a frog. On the other hand, when tadpoles are fed with thyroid gland they change into frogs sooner than usual. Too little thyroid hormone in human beings causes deformed and imbecile children. But this can be cured by giving them thyroid in pills.

CONTROL OF REFLEXES. The reactions of higher animals to changes in the environment are reflexes, just as in the case of the earthworm. Usually the message is sent through nerves, as when a worm is touched, but sometimes, as we have seen, hormones are used.

In man there are numerous familiar reflexes. We will take two examples: (1) when food is smelt saliva is secreted in the mouth; (2) when a hot object is touched the hand is quickly drawn back. Now, the chief point about a reflex is that it is automatic. A certain stimulus results in a definite movement or secretion. But our second example brings out a new point. With an effort of will you can prevent yourself snatching away your hand when you touch a hot plate. You can stop the reflex from taking place.

The explanation is as follows. The nerve path of the reflex of snatching back your hand from a hot plate is from the skin inwards to the spinal cord, up to the hind part of the brain, down the spinal cord again and out along nerves to the muscles which move the hand. But association nerve cells also carry the nerve impulse from the hind part of the brain to the front part (cerebral hemispheres). The latter can then send a counter order down to the hind part of the brain. This counter order forbids the hind part of the brain to send out its command for the hand muscles to contract and snatch away the hand from the hot plate.

It is thus clear that reflexes can be controlled by the brain. If there were no such control there would be reflex movements all the time in response to every change of light, sound, touch or smell in the environment. Orderly behaviour of an animal would be impossible. But the brain is there to stop, or *inhibit*, reflexes which are not useful. It selects those that are needed. Most of the selection is done unconsciously, but sometimes it is conscious, as in the case of the hot plate.

THE BRAIN. We know now that when a worm wriggles on being touched, the incoming nerve impulse passes over to the outgoing nerve cells in a ganglion of the nerve cord. In vertebrates the nerve cell bodies through which reflex nerve impulses pass are grouped together in definite places in the central nervous system. These are called *reflex centres*. Each reflex has a definite centre in the central nervous system.

Take what is called the knee jerk. If you sit with one leg crossed loosely over the other and tap just below the knee cap, your foot will jerk up. The nerve path of this reflex is inwards to the lower part of the spinal cord and then out again to the leg muscles. The centre for the knee jerk is towards the hind end of the *spinal cord*.

Many reflexes have their centres in the back part of the brain, the *medulla* (Fig. 14). Here, for instance, is situated the reflex centre for the secretion of saliva. Here also is the centre for controlling the width of arteries. You will remember (p. 24) that in this way more blood is sent to those parts of the body most requiring it. The stimulus for this reflex, by the way, comes not from the outside environment but from inside the body. Digested food going into the intestine wall acts as a stimulus for the widening of the arteries leading to the intestine.

The various reflex centres in spinal cord or medulla are connected by association nerve cells with parts of the brain further forward. These *front regions* are in command. They select which reflexes will be allowed to act and which not. You saw how the hot plate reflex can thus be inhibited. To take another example: if a dog's side is tickled it lifts the hind paw of that side and scratches. Supposing, while the dog is scratching, the other side of the body is tickled. Then the scratch reflex does not take place on that side. If it did, the dog would not have three legs to stand on. The front part of the brain inhibits the second reflex.

The foremost part of the brain, or *cerebral hemispheres*, is immensely more bulky in man than in the frog (Fig. 14). It is composed of millions of nerve cells (Fig. 137) connected together in complicated ways. The various parts of the hemispheres are nerve centres with different functions. Body movements and speech are controlled from here. Here is the seat of sensation and of consciousness.

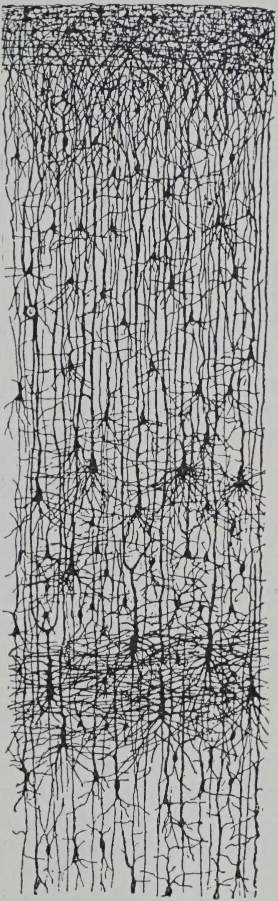

Fig. 137. *Nerve cells in the human brain.*

Eyes. Stimuli from outside affect special cells at the surface of the body. *Pressure* (touch) and *temperature* changes influence cells in the skin (Fig. 125). *Chemical* stimuli affect cells in the nose (smell) or mouth (taste) of vertebrates, in the antennae of arthropods and in the skin of worms. *Sound* is received by a complicated sense organ in the ear. *Light* may influence cells in the skin, as in the earthworm (p. 120). But in many animals eyes exist which not only give information as to the difference between light and darkness but form pictures of the outside world which are transmitted by nerves to the central nervous system.

The eyes of vertebrate animals act on the principle of a camera. There is a *lens* which forms an image on the back of the eye (Fig. 138). The image falls on the *retina.* Around the eyeball there is *black pigment* for the same reason that a camera has a black lining.

The retina consists of immense numbers of nerve cells. Each has a chemical substance in it which is changed by light. The change is temporary, not permanent as in a photographic paper. Each passing image on the retina causes chemical changes in the nerve cells, varying in amount with the quantity of light falling on each cell. The chemical changes are stimuli to other nerve cells in the retina, which as a result send nerve impulses to the brain.

FOCUSSING. A camera is focussed by moving the lens in and out. The *frog's* eye does the same. There is a *lens,* which is moved forwards or backwards to focus near or far objects. But in *mammals* focussing is done in another way. The lens can be made to change its shape. It can bulge or flatten. In some persons the lens cannot change in shape enough for efficient focussing. Then glasses are worn to supplement the eye lens.

When a camera is used in bright light, a diaphragm is made smaller to let in less light and to make the image sharper. The vertebrate eye, too, has such a diaphragm, called the *iris.* By an unconscious reflex it closes down in bright light and widens in dim. The iris is the coloured part of the eye. The *pupil* is its aperture.

VISION WITH TWO EYES. Eyes are movable by muscles so that they can be brought to bear on definite objects. Each of our two eyes sees an object from a different angle. Thus we have an impression of solidity. This is aided by perspective: distant parts of an object form smaller images on the retina than near parts.

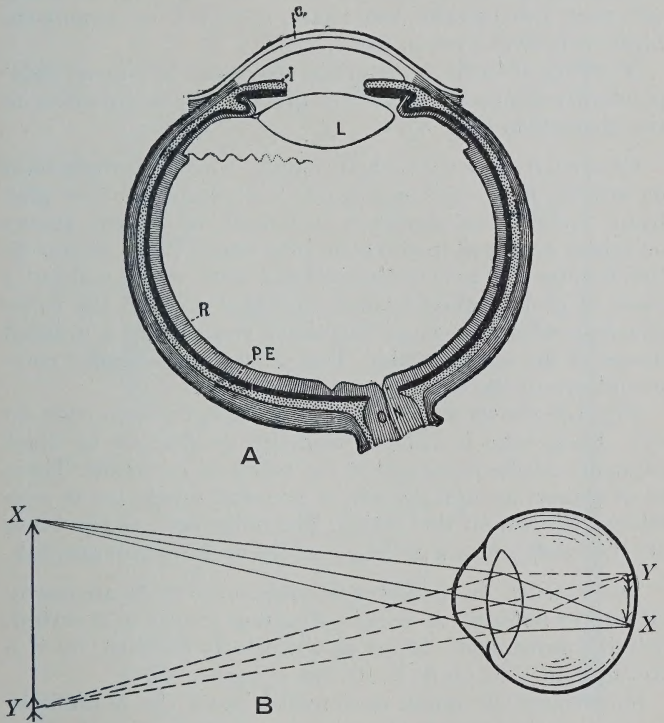

Fig. 138. *Eye of a vertebrate animal.* A, structure of eye: *c.* front surface of eye; *I*, iris; *L*, lens; *PE*, black pigment; *ON*, nerve to brain; *R*, retina. B, formation of image on retina.

Different mammals have their eyes set at different angles, some with such wide angles that they cannot bring both eyes to bear on the same object. But then the animal has a wider field of vision. Generally speaking, hunters have a small angle, hunted animals a wide angle of vision. For example, the axes of different eyes are set as follows: lion, 10°; dog, 40°; deer, 100°; giraffe, 140°; hare, 170°. So, too, among the birds owls have eyes in front.

The eyes of birds, reptiles and fishes can be moved independently of one another. This gives a very weird effect in the chameleon (Fig. 8).

COMPOUND EYES. Arthropods, whether crustaceans or insects, have eyes constructed on quite another plan from vertebrates. Imagine a bundle of hollow straws or tubes, arranged in the form of a cone. Then, if you fix this bundle in a hole in the wall of a dark room, and put a piece of ground glass against the inner ends of the tubes (the ends which are closer together), you will see a reduced image of the scene outside. This is how the so-called compound eye of the arthropod works.

Fig. 139 shows a diagram of a section through such an eye. Each tube is isolated from its neighbours by *black pigment*. At the inner end of the tubes is the *retina*. There is, of course, an upright, not a reversed image (as in ourselves), thrown on this retina. The outer ends of the tubes are the *facets* you saw in the eye of the cockroach or crayfish.

INSTINCT. In the lower animals movements are nearly all due to *reflexes*. A certain stimulus results in a certain definite movement. If an earthworm is touched, or if a strong light falls on it, it always wriggles.

Sometimes the reflex movements cause the animals to move directly towards the stimulus or away from it. Thus moths fly towards a light, while fly larvae move straight away (p. 140). This is because, when the animal gets more light on one side of its body than the other, it turns by a reflex until both sides are illuminated equally. Then it moves straight towards or away from the light.

Often a stimulus from the outside world does not result in just a single reflex. The first reflex movement may act as a stimulus for a second reflex and so on. Watch an earthworm crawling forwards. The muscles of the succeeding segments contract in turn. The shortening of one segment pulls at the muscles of the next. This is a stimulus for them

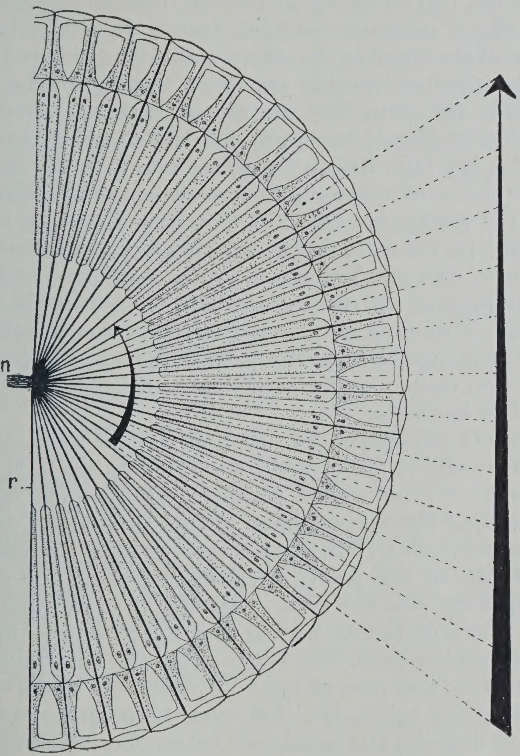

Fig. 139. *Compound eye.* Diagram of a section through the eye of a crustacean or insect. The only rays of light reflected from the arrow which can enter the eye are those that go straight down the tubes. Thus an image of the arrow is formed on the retina, *r*. The nerve from the eye is seen at *n*.

to contract. There is a *chain of reflexes,* each acting as a stimulus to the next. The first stimulus was from the outside world, the following stimuli are from inside the body.

Or take a mosquito sucking blood. It settles on your ankle and the smell of the skin is a stimulus received by the insect's antennae causing the reflex pushing of the mouth parts into the skin. This movement is then a stimulus to the salivary glands to squirt out the stinging liquid. In turn this is a stimulus to the pump which draws in blood.

Such chains of reflexes may be very complex. Think of the life of the worker bee (p. 151). You have read how it alters its habits periodically during its life. Each of its actions is a chain of reflexes. When one job is done the bee has become older and the chemical constitution of its blood has changed. This now acts as a fresh stimulus for the next duty in the hive to be performed. These complicated series of reflexes, each one following automatically on the other, are called instincts.

Instincts are *purposeful.* At first sight it looks as if the bee knew why it performed its various duties in the hive. So, too, with numerous complicated instincts of other insects. But this cannot be so. One example out of many will make this clear. There is a certain so-called mason wasp. The female of this insect prepares a hole in the ground. Having done this she goes in search of a caterpillar and stings it in a particular way so that the caterpillar does not die but is paralysed. The wasp drags the caterpillar back into the hole and lays an egg on it. Then she closes the hole with prey and egg inside. Later on the wasp larva hatches out and devours the paralysed caterpillar. But the wasp never sees this, nor has she ever seen another wasp preparing a caterpillar and laying an egg. She never has any opportunity of seeing the purpose of her complicated instinctive action.

Instincts are automatic reflexes. Each individual bee or wasp behaves in the same way. The instincts are *inborn* just as much as bodily structure is inherited. And it is not only insects that have instincts. The stickleback, for instance, is a fish of which the male builds a nest of pond weeds and guards the eggs. Birds have mating and nesting instincts. In the mammals one of the most complicated instincts is that of beavers. These animals build dams to make pools of water, in which they store parts of trees with the bark on them for food. They fell the trees and cut them up. And they construct canals so that water flows down to the pool and so conveys the logs. There are innumerable other examples of instincts.

The essence of an instinct is that each individual animal of a species does the same thing. Yet instincts are not quite unchangeable. They can be *modified* during the lifetime of an animal. There are two ways in which animals behave otherwise than by pure instinct: (1) animals have memory and can learn, and (2) some animals can reason.

FORMATION OF HABITS. Even animals as low in the scale as earthworms form habits. A worm was put, head end first, into one branch of a Y-shaped tube. It crawled forwards and at the fork had to go to right or to left. In the right-hand branch wires were arranged so that the worm got an electric shock if it took that path. Five such experiments were made daily. At first the worm went as often to right as to left. But after 150 trials it had learnt to go to the left, making only 10 per cent. of errors. More complex animals than worms have much greater powers of learning and of forming habits.

CONDITIONED REFLEXES. Instincts, as you know, are more or less complicated chain reflexes. Both instincts and simpler reflexes can be modified by the formation of habits. Take the case of the secretion of saliva. When a dog smells or sees food, its mouth waters and its tail wags. The stimulus for this reflex is the smell or sight of food. The secretion of saliva is a reflex response. Suppose now that food is offered to a dog and at the same time a bell is rung or a light flashed on. After this has been repeated a few times the bell or the light alone (that is to say without the food) causes the saliva to be secreted. Instead of the original food stimulus, a new stimulus, the bell or the light, now calls forth the reflex. This is known as a *conditioned* reflex.

We will take another case. It concerns bees. A number of differently coloured cards are put out on the ground near a hive. On each card is a watch glass. The watch glass placed on one particular colour, say blue, has sugar and water in it. The others are empty. After some chance visits, the bees find the sugar. Then it is noticed that on their following visits they fly straight to the sugar. Next the sugar is removed from the blue card and an empty watch glass is put in its place. Still the bees make straight for this card. A conditioned reflex, or rather chain of reflexes, has been formed, blue colour being the new stimulus. The bee has learnt that blue means food. It has formed the habit of coming to blue.

THE COLOUR SENSE OF BEES. Incidentally this is the way to find out which colours bees can distinguish. For example, they do not mistake a bluish green or a yellowish green card for pure green. Nor do they confuse green with any shade of grey. It turns out in fact that they recognize the same colours as we do, with two exceptions. Bees cannot tell red from black. To them red is not a colour. This must be the reason why few flowers are pure red. Red flowers have yellow or blue mixed with the red. And bees can see a certain colour which is invisible to us: they can see the ultra-violet as a colour.

INHIBITION. You have heard how important inhibition is in controlling reflexes. The brain stops unnecessary reflex movements. The same thing happens in learning. Suppose that a conditioned reflex is formed in a dog as already described. A certain musical note is sounded when food is offered to the dog. After a number of repetitions, the dog secretes saliva at the sound of the note alone, without any food appearing. But at first this secretion occurs not only at the sound of the *particular* note which accompanied the food, but for *any* note. Then the experiment is repeated again a number of times, the particular note being sounded each time the food is offered. After this, when notes are sounded without food, the dog no longer responds to *any* note, but only to the right one, or to notes very near to it. After a third trial, only the definite note which actually went with the food causes mouth-watering. This means that the first-formed conditioned reflexes to the wrong notes have been inhibited by the brain. In other words, the dog has learnt that a particular note means food. This is how we ourselves learn. We gradually become more and more accurate. The brain inhibits faults.

FORGETTING. You see now how worms, bees or dogs learn to do particular things. This is no different from the training of circus animals. By rewards or punishments they are taught to do tricks. All through its life an animal is itself acquiring such habits. We ourselves are all the time forming conditioned reflexes without knowing that we are doing it. Take just one example. An infant by accident touches a hot object, say an iron for ironing clothes. By a reflex it snatches back its hand. Next time on merely seeing the iron the child draws back its hand.

But habits are not quite permanent. They can be forgotten. A dog, for example, which has formed the conditioned reflex of mouth-watering when a bell is rung, loses this response after a time if food never accompanies the bell. It is easy to imagine how necessary this losing of habits is in the life of an animal. A fox may form a series of conditioned reflexes taking him somewhere where chickens are to be had. But if after a time no more chickens are there, he would waste his time if the old habit continued.

INSTINCTIVE LIVES. We call insects and mammals "higher animals". All, in their own way, are complicated in bodily structure and complex in behaviour. But the lives of insects are very largely directed by pure instincts while mammals can greatly modify their instincts. They are more individual. It is true that bees can learn, as we have seen, but in a hive all the workers behave almost exactly in the same way as one another. The complicated series of actions they perform are all inborn chain reflexes. A bee isolated alone in a comb does just the same things as her sisters in the hive and just as well, although she has never been educated. There is no central government in the hive. The inhabitants all do the right thing at the right time through inborn instincts. But mammals learn as they grow older. Their instincts are modified and added to by numerous conditioned reflexes. And more than this. In some few mammals reason, too, comes into play.

REASON. By reasoning we mean an understanding beforehand of what will happen if certain things are done.

A chimpanzee has been given the following problem. A banana was hung by a string from the ceiling. There were three packing cases in the room. The chimpanzee wanted the banana. How was it to get at it? After looking at the banana, the chimpanzee took the cases and piled them up one on top of the other. Then it climbed up and got the banana. Evidently the ape foresaw the result of its actions. Monkeys, too, can do this (Fig. 140).

Similar problems have been tried on dogs to try whether they can size up a simple situation, come to a conclusion, and act on it. The problem must of course be suited to what a dog can do. For instance, meat is placed within sight and smell, behind a wire fence which has a gap in it. The gap is a little way along, but in sight of the dog. Very seldom will the animal grasp the fact that it can get the meat by making straight for the gap. Nearly always it runs up and down and perhaps by chance finds the gap. Then it may form a conditioned chain of reflexes and next time go straight for the gap. Beware of concluding that because your dog can do clever things it can reason. You must be sure that it has

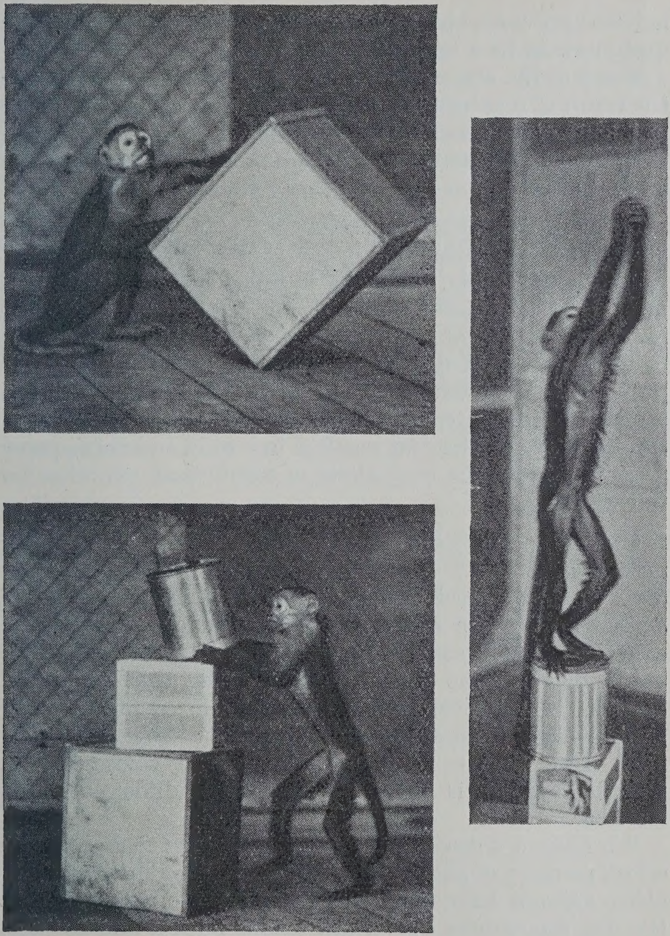

Fig. 140. *Reasoning power of a monkey.* The monkey piled up the boxes and got a banana hung on a string. It had never faced this problem before. (Bierens de Haan.)

not had previous chance experience. The problem must be quite new to be a test.

Many of the actions of man, though by no means all, are the result of reasoning. Apes and monkeys can solve simple problems. But other mammals can reason very little, and the power of reasoning seems to be rare in the rest of the animal kingdom.

INTELLIGENCE. I have not used the word *intelligent* at all. This is because intelligence is used in different senses by different people. If a dog is called intelligent, it may mean that its master thinks it can reason. On the other hand, an intelligent dog may be one which quickly learns to form habits. A dog shows signs of joy when its master puts on his overcoat because this is a stimulus which has already formed a conditioned series of reflexes. The first time, putting on the coat resulted in a walk and consequent pleasure. Now the coat alone is a sufficient stimulus for tail-wagging.

CONSCIOUSNESS. Are animals conscious of their actions as we are? Have they a consciousness of present events and a conscious memory of past happenings? We cannot know. Nor can I be certain that my neighbour is conscious. But I assume that he is so, because his actions are similar to mine and his brain has the same structure. So, too, it is logical to conclude that in so far as other animals have a brain like ours they have some consciousness. But what can we say of an insect whose central nervous system is made on a totally different plan? Nothing.

We have a consciousness of present events and a conscious memory of past events. But we cannot know whether other animals have conscious memory. We may say that the dog remembers that a bell means a meal and so wags his tail and secretes saliva. It may or may not be true that he has a conscious memory of this. All we can know for certain is that a conditioned reflex has been formed. So, too, we could say that the bee remembered that a blue colour meant sugar and that the worm remembered that the right-hand turn led to an electric shock. But this way of putting it gets us no farther forward.

If insects have a consciousness, however, many of their impressions must be inconceivable to us. What sort of colour is the ultra-violet light that a bee sees? We cannot imagine. Again, for us sight and touch are among the most important senses. Our brains combine the impressions received from each. We see an object and know that it is hard. We touch something and know that it will look round. But in insects smell and touch are the most important senses. Are an insect's ganglia conscious of round and square scents, hard and soft smells?

CONCLUSION. It appears, then, that the actions of most animals are of the nature of inborn reflexes. These reflexes may be complicated chains, the result of one being a stimulus for the next. And they may be purposeful, in which case we speak of instincts. But inborn reflexes can be modified, sometimes more and sometimes less, by the formation of conditioned reflexes during the lifetime of individuals. In other words, animals learn and acquire habits. And a very few kinds of animals, particularly man, can reason and act accordingly.

## *CHAPTER XVIII*

# FOSSILS

LIFE has existed on the earth for an immensely long time. The remains of animals and plants have been found which lived not thousands but millions of years ago. These remains are found in the rocks.[1] They are called fossils. Most fossils are the hard parts of animals, the shells, skeletons and teeth. The Frontispiece is a photograph of a fossil skeleton as it was found in a rock.

EXTINCT ANIMALS. Most, but not all, of the numerous different kinds of animals whose remains are found in the rocks are no longer to be found alive on the earth. They are now extinct. The fossil bones of these extinct animals tell us that most of them were different from any animals living to-day.

Some animals are of course becoming extinct now, and in the course of the last few centuries animals once wild in England have disappeared. In the time of Henry VIII there were wolves in this country. To-day there are none. Up to about the same time beavers were found in England. Now they have vanished, although wolves and beavers are still found wild in other parts of Europe.

But there were animals existing at the time when prehistoric man lived which are now quite extinct. A large kind of elephant called the mammoth was formerly very common all over northern Asia and Europe. It had long coarse hair and huge curved-up tusks. Although mammoths and prehistoric men lived side by side, mammoths long ago died out. Yet complete carcasses of mammoths, with skin, hair, trunk, muscles and bones, have been found frozen in Siberia. Most fossils, however, are the remains of animals and plants which died out long before the mammoth.

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[1] The science of rocks is known as geology.

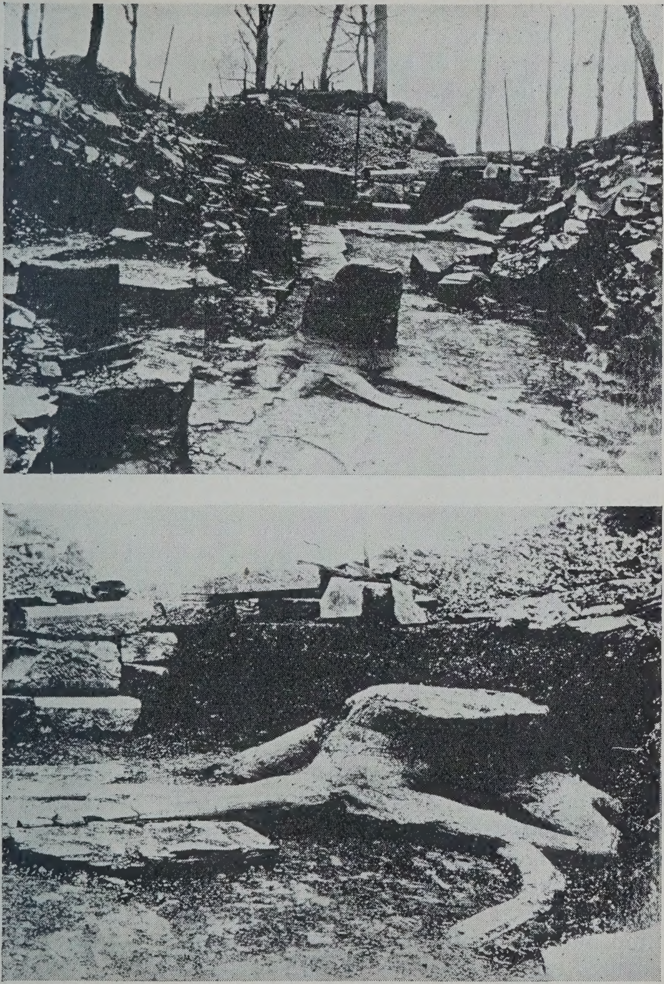

Fig. 141. *Fossil tree trunks and roots.* These trees lived in a Coal forest about 300 million years ago. The photograph was taken in Glasgow.

THE ORIGIN OF FOSSILS. How has it come about that the remains of extinct animals are found as fossils embedded in rocks?

Rivers, flowing to the sea, carry with them immense quantities of mud in suspension. The Amazon, for instance, which is 70 miles wide at its mouth, discharges 1870 tons of solid matter per minute. At the mouths of the rivers this sediment is deposited on the sea bottom. The bigger particles of sand fall first. The finest mud is carried farther out to sea by currents before finally it falls on the sea bed.

When marine animals die, their carcasses fall to the bottom of the sea. If they are not chewed up by other sea creatures, the dead bodies will slowly be covered up by the falling mud. The same fate will happen to the carcasses of any land animals which have floated down with the rivers to the sea. In the mud the soft parts of the dead animals soon putrefy. They are destroyed by bacteria. But the hard skeletons remain.

As layer upon layer of sediment is laid down, the mud or sand beneath is slowly turned into hard rock by the pressure of the layers above. The mud becomes clay, the sand is turned to sandstone. And slowly the bones or shells buried in the sediment are changed to fossils. The actual calcium carbonate of shells and calcium phosphate of bones, for example, is replaced by crystalline calcium carbonate.

It is not only animal remains which can become fossils. Plants may also be preserved. Coal is formed from the remains of forests. Tree trunks are found in the rocks which have layers of coal in them (Fig. 141). Fossil leaves, too, are found in the rocks which were once mud in the swamps where the coal plants grew (Fig. 142). Sometimes even clear traces of the soft parts of animals are preserved in rocks (Fig. 143). The dead animal may have lain on soft mud and the impression which it left have been quickly covered up by more mud brought by a current.

Far out on the ocean floor deposits are also formed. There is no sediment from rivers in the clear water there.

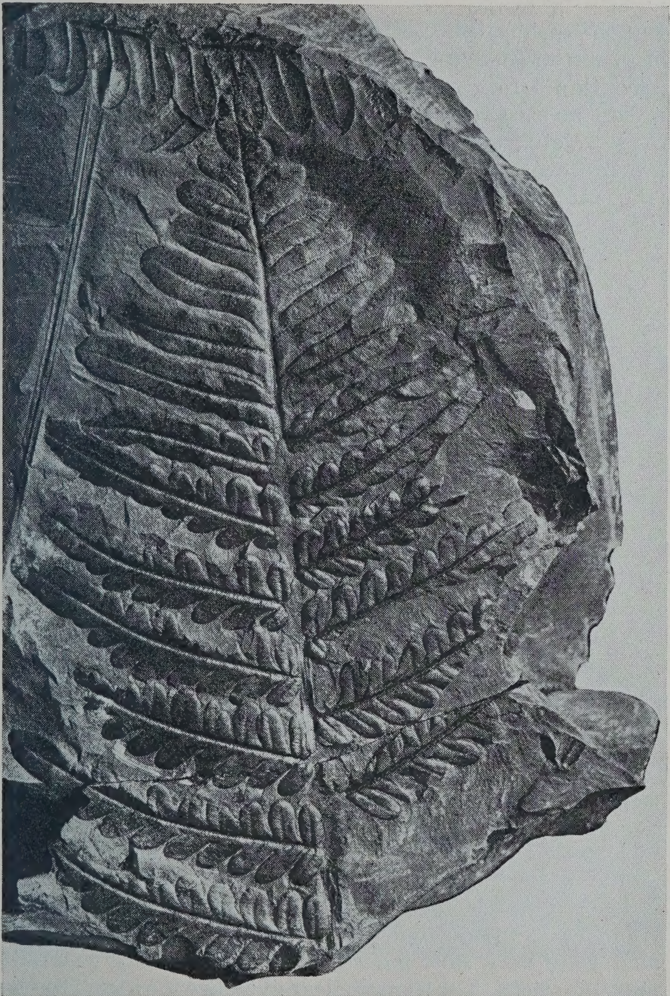

Fig. 142. *Fossil plant.* The photograph shows the frond of a fern which lived in a Coal forest.

But the surface waters of the ocean contain vast quantities of plankton (p. 226). As the plankton animals die, there is a continual rain of their small skeletons falling on the ocean floor. Crustaceans, like *Calanus*, and larvae of oysters, etc., are too fragile to make fossils, but there are protozoa with beautiful shells of calcium carbonate (Fig. 144) in the plankton. These slowly accumulate on the ocean bottom, in the end becoming rocks made up almost wholly of these tiny fossils. Chalk is such a rock. Some kinds of chalk are largely composed of such minute fossil shells.

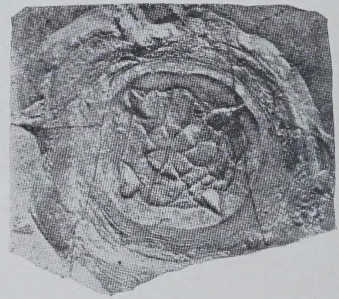

Fig. 143. *Photograph of fossil jelly-fish* (p. 112). The impression of the soft animal remains in this Secondary Era rock which was once mud.

Earth movements. You see now how rocks are formed from sediment and how fossils may be included in these clays, sandstones, or chalk. But how is it that the rocks with their fossils are now found above the sea, even on mountain tops?

The reason is that the crust of the earth is not stationary. It moves up and down in different places. True, these movements are very slow indeed, so slow that they generally pass unnoticed. Yet there is clear evidence that such movements do take place. On the east coast of England there

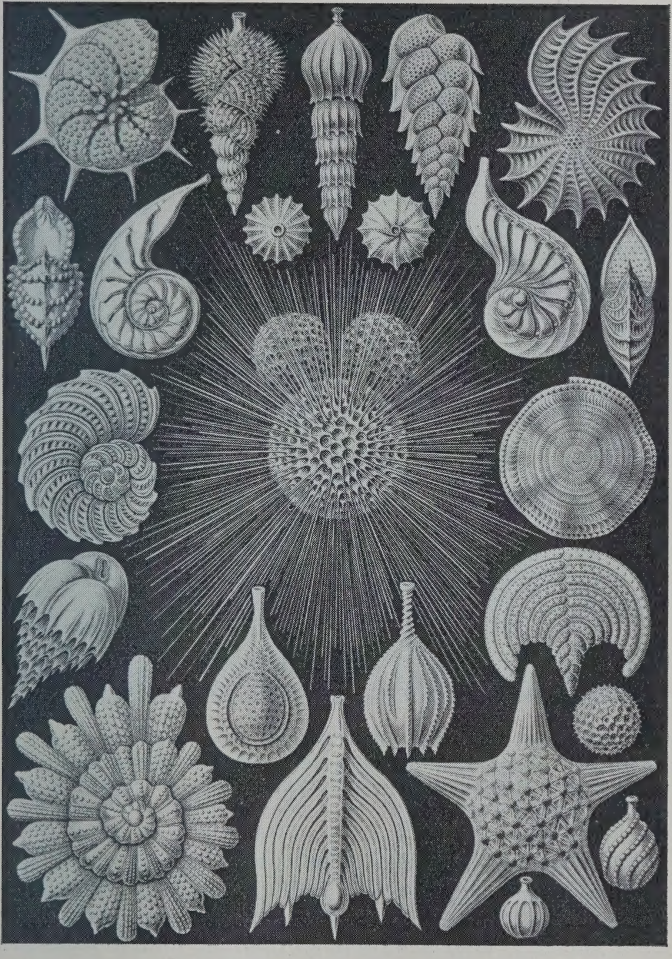

Fig. 144. *Shells of protozoa living in the plankton.* These are magnified drawings of the shells, which were just visible to the naked eye.

are ruined buildings now under the sea. At many places on our coasts there are pebble sea beaches now well above the reach of the waves. At Pozzuoli near Naples there is a ruined Roman temple. The lower parts of the columns are riddled with small holes. These were made by marine molluscs. Their shells are still in the holes. This proves that after Roman times the temple sunk below sea level. Now once more the land has risen, so that the temple ruins are again above the sea.

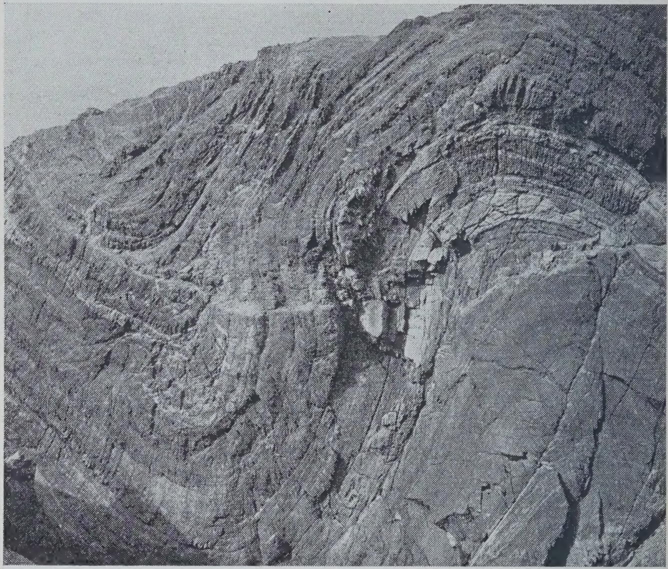

Fig. 145. *Photograph of strata.* This is a cliff in Pembrokeshire. The strata were originally horizontal layers of mud deposited under the sea. They were later on hardened to rock, and then raised up and bent by earth movements.

The temple at Pozzuoli has moved down and up again during the Christian era. But these two thousand years are nothing at all in comparison with the millions of years that life has existed on the earth. All this time slow movements of the earth's crust have gone on. Layers, or *strata*, of rocks laid down from sediment under the sea have been slowly raised up above the sea level. Thus mountain ranges are formed.[1] Sometimes the movement is more violent. Then earthquakes result. In the raising and folding process the strata, originally horizontal, often become bent and curved (Fig. 145).

PAST AGES. It is clear now that when a number of layers (strata) of rock are exposed in a cliff or quarry the upper layers of these stratified rocks are younger than the lower layers. For the sediment was gradually laid down in the sea, one layer on top of the other. By comparing one cliff with another it has been possible to construct a complete section or diagram of all the strata on the earth's surface. Fig. 146 shows such a section. The top strata are the youngest, the bottom ones the oldest. Obviously the thickness of each kind of rock is roughly a measure of the time it took to be laid down in the sea. Actually we know that the Chalk was formed some 100,000,000 years ago. Coal dates 300,000,000 years back, and the lowest strata containing fossils (the Cambrian) are 600,000,000 years old.[2]

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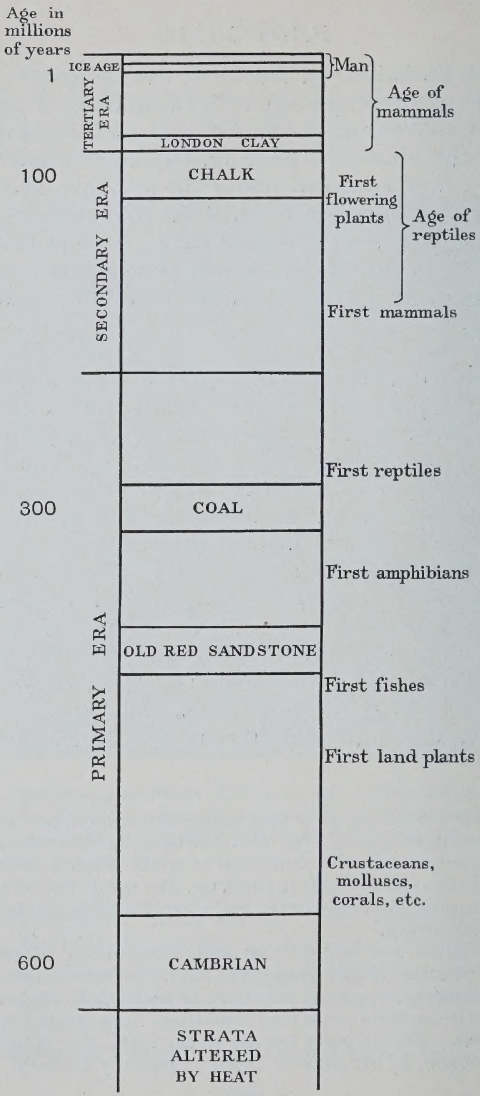
[1] After the rocks have thus been raised up into hills and mountains they are slowly worn away by rain. Carbonic acid in the rain water helps this process, and the expansion of water when it freezes in the cracks of rocks aids in breaking them up. The resulting soil is washed down by streams and rivers to the sea, where the sediment is deposited to form fresh strata.

[2] These dates are found from the composition of radioactive minerals. Uranium slowly changes to lead. The rate of this change is known. Uranium ores from intrusive igneous rocks high up in the series of strata contain more lead than those from strata lower down. The proportion of lead gives the age of the rock. For details see *The Age of the Earth*, by A. Holmes, Benn's Sixpenny Library.



Age in millions of years
1
100
300
600
ICE AGE
TERTIARY ERA
LONDON CLAY
CHALK
SECONDARY ERA
COAL
OLD RED SANDSTONE
PRIMARY ERA
CAMBRIAN
STRATA ALTERED BY HEAT
Man
Age of mammals
First flowering plants
Age of reptiles
First mammals
First reptiles
First amphibians
First fishes
First land plants
Crustaceans, molluscs, corals, etc.

Fig. 146. *Table showing the strata of rocks with their approximate ages.*

During this immensely long series of ages the climate of each part of the world has changed a number of times. In Britain, for instance, the climate has sometimes been much warmer, sometimes much colder than it is at present. During the age when the Coal forests flourished the climate was warm. Later it became temperate again, but at the time when the London Clay (Fig. 146) was deposited the sea was tropical. This is proved by the nature of the fossils. Coral reefs flourished in the sea which then covered part of England and we know that reef-making corals only live in tropical seas. Later on there was an Ice Age. The whole of northern Europe was covered by glaciers. In England they extended south as far as the Thames valley. Rocks scratched by this ice can be seen to-day.

Man has only existed on the earth for a relatively short time, short, that is to say, in comparison with the periods of time we have spoken of. Human beings have been on the earth for a paltry million years. Fossil remains of human skeletons have been discovered in a number of places and the stone tools and weapons which early prehistoric man made are found widely spread. The strata in which these remains have been found prove that primitive man was on the earth before the Ice Age, but not very long before that time. Early human beings differed from modern men in a number of ways. Their brains were considerably smaller. In appearance they must have somewhat resembled apes.

FOSSIL HORSES. As an example of what fossils can tell us about animals which existed in past ages we will take the case of extinct horses. You will remember that the horse really walks on the middle finger and toe of each limb (p. 242). On either side of each cannon bone (third metacarpal or metatarsal) is a splint bone. The splint bones are really the second and fourth metacarpals or metatarsals.

But at the beginning of the Tertiary Era (Fig. 146) horses had five toes, not one. Fig. 147, A shows the skeleton of the fore foot of a horse which existed a little later than the earliest five-toed horse. You can see that its three middle toes touched the ground, but that the first and fifth did not do so. Fig. 147, B shows a horse which lived in the middle of the Tertiary Era. It walked on its middle toe only, but the second and fourth were still big. The first has disappeared, however, and the fifth is a mere splint bone. Fig. 147, C gives the foot of a later fossil horse, which was almost the same as the modern horse.

The oldest horses of this series were no bigger than greyhounds. As we ascend the Tertiary strata each successive kind of horse gets bigger in size at the same time as its limbs are more and more specialized for rapid motion.

Not only can such a series of extinct horses be traced back into past time. Other animals, elephants and the camel for instance, have the same sort of past histories. As we go down in the strata of rocks, elephants become gradually less and less like the modern elephant. At the same time they have less and less of the specialized structures, such as trunk, tusks and crushing teeth. The further back we go in time the less do fossil elephants differ from other mammals.

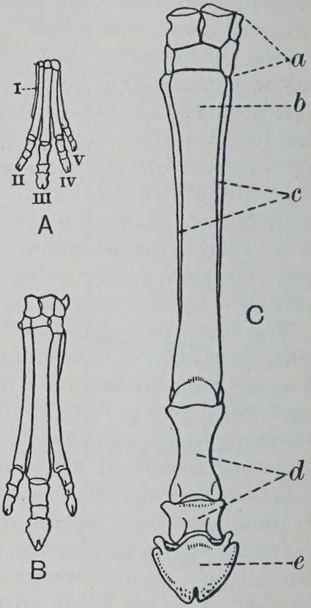


Fig. 147. *Fore feet of fossil horses.* A, the oldest, existed at the beginning of the Tertiary Era. B is younger, and C, the youngest, lived just before the Ice Age. *a*, wrist bones ("knee"); *b*, third metacarpal (cannon bone); *c*, second and fourth metacarpals (splint bones); *d*, finger bones; *e*, nail (hoof).

EXTINCT REPTILES. The oldest fossil horses and elephants are found at the beginning of the Tertiary Era. During all that Era, as to-day, mammals were the most abundant large animals on the earth. But earlier than the beginning of the Tertiary Era very few mammals existed at all and they were very small in size.

During the long Secondary Era, however, reptiles were very abundant. Many of them were quite different from any reptiles alive to-day (p. 237). And many of these reptiles of the Secondary Era were huge in size. They took the place on the earth later on occupied by mammals. But at the end of the Secondary Era, at the time when the Chalk sea extended over England, these giant reptiles died out. They became extinct.

Mammals to-day are some of them flesh eaters, others vegetable feeders. Among the mammals, whales and seals live in the sea, while bats fly. So, too, in the Secondary Era there were huge carnivorous and herbivorous reptiles. And there were others which swam in the sea and yet others which flew.

The huge land reptiles belonged to a group of reptiles called *dinosaurs*. The first fossil skeleton of one of these animals was found in Sussex. It was herbivorous, and it stood on its hind legs like a kangaroo. Its head was fourteen feet from the ground. There were also carnivorous dinosaurs of much the same build (Fig. 148). The fact that they were carnivores and the others herbivores is known from the nature of their teeth. Just as lions prey on antelopes to-day, so one kind of dinosaur hunted another. The dinosaurs laid eggs, in the same way as crocodiles and some snakes do.

There were also enormous dinosaurs which went on all fours. The skeleton of one of these is in the Natural History Museum in London. It is eighty feet long. Nevertheless, these giant reptiles are not the largest animals that have ever lived. The biggest whales are one hundred feet long and they are very much bulkier.

A most interesting fact about these giant reptiles is that they all had very small brains. Perhaps one of the chief reasons why they died out was that they could not compete with the more cunning mammals when these became abundant on the earth.

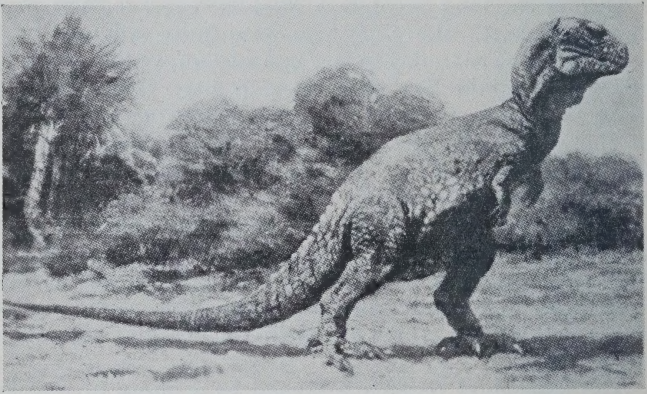


Fig. 148. *Carnivorous dinosaur.* This is what the animal probably looked like. It was eighteen feet high.

*Ichthyosaurs* were marine reptiles. Their structure was as completely adapted to life in the sea as that of whales (p. 244). The limbs were paddles, although they had the usual limb bones of vertebrate animals. There was a fin on the back and a tail fin. Specimens have been found with the skeletons of young inside them. This shows that the ichthyosaur brought forth its young alive. The Frontispiece to this book shows such a specimen with a newly born young one just behind it, and the bones of three embryos inside the body of the mother. Just as in the case of the other young vertebrate animals, the head and eye of the new-born ichthyosaur was very large compared with the size of its body. You can see this in the photograph.

Perhaps the most astonishing extinct reptiles were those which flew. They are called *pterodactyls* (Fig. 149). The wing was constructed on a different plan from those of birds or of bats. The fourth finger was enormously long and a membrane of skin extended from it to the side of the body and the leg (Fig. 129). Some pterodactyls were of the size of crows, others had a wing span of twenty-five feet. The wings of a Moth aeroplane measure only fifteen feet across. But pterodactyls can better be compared with gliders. The small size of the keel on their breast bone shows that the flying muscles were not well developed. It follows that the huge wings must have been used largely to glide and soar, making use of upward air currents like glider aeroplanes

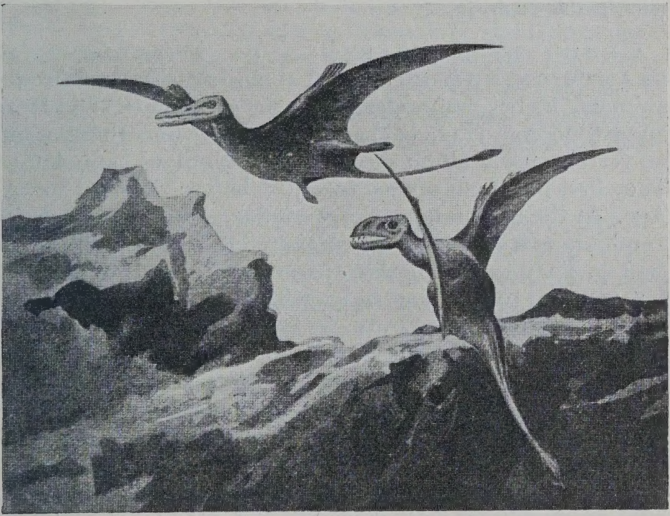


**Fig. 149.** *Pterodactyls.* **Two kinds of flying reptiles as they must have appeared.**

and some birds such as kites. They probably "took off" from cliffs.

Fossil birds. Birds have existed on the earth from the Secondary Era onwards. No living bird has teeth, but the earliest birds had teeth like reptiles. Moreover they had long tails. The tail was something like that of a lizard with feathers on it.

Order of appearance of animals and plants on the earth. Let us take the vertebrate animals. Fishes first appeared on the earth in the Old Red Sandstone Age (Fig. 146). Before that time there were no vertebrates at all on the earth. Amphibians came later. They first put in an appearance just before the Coal forest Age. At the beginning of the Secondary Era some kinds of amphibians were very large compared to the amphibians of to-day. They were something like newts (p. 232) to look at, but were up to nine feet in length. Soon afterwards these giant amphibians died out.

The great age of reptiles was the Secondary Era. The first reptiles existed before the beginning of that age. Mammals and birds first appeared on the earth later than reptiles. During all the Secondary Era, however, mammals were not only few in number but they were small and insignificant. Then, in the Tertiary Era, mammals of all sorts appeared. The giant reptiles had died out and mammals replaced them as the lords of creation. It was not until right at the end of the Tertiary Era that man arrived.

You will notice that the order in which the various classes of vertebrates appeared on the earth is the same as the order in which we arrange the classes from the point of view of complication in structure and efficiency in function: fishes, amphibians, reptiles, birds and mammals, and finally man. In past ages, amphibians, reptiles and mammals each flourished and dominated in turn as land dwellers. Mammals, with their controlled body temperature and better brains, had the last triumph, with man at the end of the story.

While reptiles were the masters, not only were many of them huge in size, but they were of all varieties, vegetable and flesh eaters, swimmers and fliers. So, too, in a later age there were all sorts of large and small, herbivorous and carnivorous, mammals, with whales and bats.

Land plants tell the same story. The remains of flowering plants are found no lower than the Chalk Age. The Coal forests were formed by plants resembling giant ferns and by other flowerless plants which afterwards died out. Flowering plants are better adapted to land life than ferns, for they have seeds (p. 183). So flowering plants succeeded, and gradually appeared in all varieties and forms to take possession of the land.

THE BEGINNING OF LIFE. What animals inhabited the surface of the earth before the fishes, the first vertebrates to appear? Below the first fossil fishes found in the strata of rocks there are numerous remains of animals other than vertebrates. Before the fishes there were already corals, molluscs, crustaceans and many others. Fossils of these are found right from the bottom to the top of the series of rocks. As with the vertebrates, the further we go back in time, the less like were these creatures to animals alive to-day.

But it is quite sure that this planet was populated long before the Cambrian Age (Fig. 146), long before the rocks containing the oldest fossils. Why is it then that we find no fossil remains of these oldest animals?

The centre of the earth is composed largely of molten rock. Sometimes this comes to the surface in volcanoes. When this central rock solidifies, it is crystalline. Granite is such a rock. Now the oldest strata of rock containing fossils have in past ages been forced down near to the hot central rock. The mass of strata above, and movements of the earth's crust, have been responsible for this. The result is that the lowest layers of rocks which once contained fossils have been literally cooked. The heat below and the pressure above has made them re-crystallize. Slate is clay changed in this way. Limestone becomes marble.

But in this process all fossils are destroyed.[1] The unfortunate result of this is that we can never know what the animals or plants were like which lived before the Cambrian Age. No fossils remain to tell us. We are sure only that there was life existing on the earth for a very long time before the Cambrian Age. Probably the time from the beginning of life on the earth until the Cambrian was quite as long as all the ages from the Cambrian until to-day.

## PRACTICAL WORK

Search for fossils in cliffs or quarries of stratified rocks, taking a hammer and cold chisel with you, and, if you have the opportunity, go to the Natural History Museum in London and look particularly at the fossil vertebrates.

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[1] There are marbles of later date than Cambrian in which fossils can be seen. These are limestones which have only been partially altered. They are often seen in mantelpieces.

## *CHAPTER XIX*

# EVOLUTION

### I. THE FACT OF EVOLUTION

THE numerous different breeds of dogs are descended from a kind of wild dog like a wolf. In the course of time the various different breeds, bulldogs, dachshunds, greyhounds and so on, have arisen. Biologists believe that this is true not only of dogs and other domestic animals. They believe that all the different kinds of wild animals and plants have a similar past history. To-day there are over a million different species of animals and plants on the earth. These are believed to be descended through the ages from other animals and plants. This process of descent is known as evolution.

There is an immense amount of evidence for the truth of evolution. We shall examine the facts shortly in this chapter. Much of the evidence has been given already in previous chapters, and so we shall have continually to be referring back to facts which you know already.

THE FAMILY HISTORY OF HORSES. You have seen how plants and animals are classified into species (p. 216). When this classification has been made, the questions arise: What is the past history of a species? If we trace the succeeding generations of a particular species of animal or plant back into the past, were the individuals always exactly like those which are alive to-day? Or were they once different?

If now you think of the several extinct species of horse (p. 291), an answer to the questions at once suggests itself. You will remember that as we descend downwards in the strata of rocks, that is as we go backwards in time, the fossil horses get less and less like horses alive to-day. At the same time the further back we go the less were fossil horses different from other mammals. Think of the gradual change from one-toed to five-toed feet as we pass downwards. Similar series of species, succeeding one another in time, are known for elephants, camels and other animals and plants.

The questions are these: Are we looking at long family histories? Are modern horses descended in a direct line from a five-toed animal in the early Tertiary Era? Or has each succeeding species of horse been created independently, lived for an age and then died out to be replaced by a new creation? Biologists believe that the first of these two alternatives is the correct one.

The three different species, horse, ass and zebra which are alive to-day have a past history like that of the different races of dogs, although of course a history immensely longer. The different breeds of dog all arose during the course of human history. The dog breeds are all descended from a wild species of dog, each breed becoming more and more unlike the wild dog as time goes on. So modern horses, asses and zebras are believed to be descended through the various fossil species of horse from a small five-toed ancestral species which lived in early Tertiary times.

Not only is this true of horses. All living species of animals and plants are believed to be descended from other species now extinct. Comparison with the known history of domestic animals and cultivated plants points to this, and so do the series of fossils found in rocks of succeeding ages. We shall now look a little more closely at the various other lines of evidence which have led to the same conclusion.

FLYING VERTEBRATES. Consider the wings of different flying vertebrate animals. Pterodactyls, birds and bats each have wings (Fig. 129). The wing skeleton of each has in it the bones found in the fore-limbs of other vertebrates. These are the humerus, radius and ulna, wrist bones, metacarpals and finger bones. But in each of the three kinds of wings certain bones are enlarged, others are suppressed. And in each kind it is different bones which do the work of flight.

The explanation is that the three kinds of flying vertebrates were each evolved separately from non-flying kinds. Pterodactyls and birds each descended from different types of reptiles. (The fossil bird with teeth and tail (p. 296) is an ancestor of modern birds—it is intermediate between present-day birds and reptiles now extinct.) Bats came from mammal ancestors not unlike shrew mice.

SWIMMING REPTILES AND MAMMALS. The limb bones and muscles of the different flying vertebrates have been in each instance modified and adapted in a special way for flight. So, too, we have met with both reptiles and mammals which are aquatic. These are the ichthyosaurs (p. 294) and the whales (p. 244). Here again the limbs, with the usual vertebrate limb bones, have been modified for a special purpose. The limbs form paddles or fins, but in them we can recognize the same bones as are present in the legs of walking and flying reptiles and mammals (Frontispiece and Fig. 128).

The explanation is that ichthyosaurs were the modified descendants of terrestrial reptiles and whales are descended from land mammals.

INSECT MOUTH PARTS. Another example of modification of structures to meet special ends is supplied by the mouth parts of insects (Chap. x). You saw how the same mouth parts can be recognized in cockroach, butterfly, fly and mosquito, but in each they are differently shaped for special purposes.

INDEPENDENT EVOLUTION OF WINGS AND OF EYES. Insects fly, but their wings are constructed on a totally different plan from those of vertebrates. Arthropods, whether they be insects or crustaceans, and vertebrate animals each have eyes. But, as you know, the principles on which the eyes work and their structure are widely different in arthropods and vertebrates.

The explanation is that both the wings and the eyes of arthropods and of vertebrate animals have each been evolved separately and independently in types of animals quite unlike one another in structure.

UNUSUAL FUNCTIONS OF ORGANS. You see now how the fore-limbs of flying and swimming vertebrates have taken on new functions in the course of ages. The corresponding limbs of the ancestors were for walking. There are numerous other examples of organs which have one use in most species of a group of animals or plants, but an unusual function in certain other species. These instances can be explained by evolution, by descent with change of function.

For example, the poison gland of a snake is a modified salivary gland (p. 237), and the milk glands of mammals are sebaceous glands with a new secretion (p. 239). The antennae of most crustaceans are sense organs, but in *Cyclops* and *Daphnia* (p. 224) they are used for swimming. In the barnacle (p. 229) the limbs serve only for food catching. In flowers, not only petals and sepals, but stamens and carpels also, are modified leaves (p. 158).

VESTIGIAL ORGANS. Often we find an organ in one species of animal which is small in size and has no function at all, while in other species of the same group of animals it serves a purpose. Such useless organs are called vestiges.

The appendix in man (Fig. 3) is a well-known case. In grass-eating mammals it is large and is concerned in digestion. Whales (p. 245) have vestiges of hind-limbs. In their ancestors these had a use. Think also of the splint bones of horses. In ourselves there are the vestiges of muscles for moving the ear lobes. Some few people can use them. In the ancestors of all these animals the now useless organs had a use. In their cousins the organs have a use to-day.

Structures in embryos. In the embryos and larvae of animals there are structures which can only be explained by evolution. Fishes have gills, they have arteries running to each gill and a simple heart with one auricle and one ventricle (p. 234). Tadpoles have the same arrangement, but when tadpole turns into frog the gills have disappeared and the blood system is altered (p. 253).

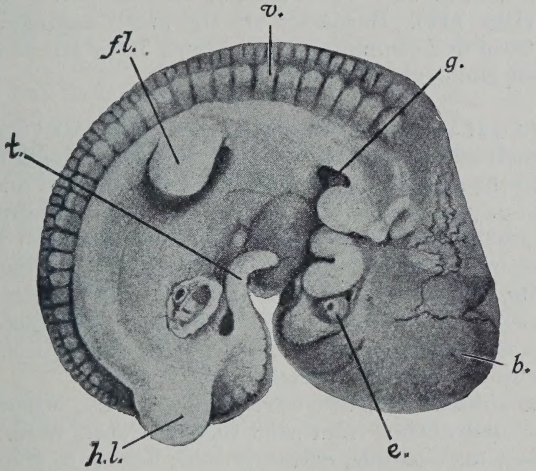

Fig. 150. *Young human embryo.* *b.* brain; *e.* eye; *f.l.* fore-limb; *g.* gill slit; *h.l.* hind-limb; *t.* tail; *v.* vertebrae.

But much more surprising than this, the embryos of both birds and mammals, including man himself, have gill slits (Fig. 150) and a two-chambered heart. In these embryos, unlike the tadpole, the gill slits are never of any use. Later on in development they disappear. This means that the land vertebrates once had fish-like ancestors. And still, while they are embryos, birds and mammals continue to pass through a stage which their aquatic ancestors passed through when they were embryos.

There are other cases of the same thing. The human embryo at one stage has a tail (Fig. 150). Flat-fishes are peculiar in lying permanently on one side. When young, however, they swim like other fishes (Fig. 124). The crab has a reduced abdomen tucked in underneath its thorax. As a larva its abdomen sticks out like that of a lobster (Fig. 115). Barnacles could hardly be recognized as crustaceans at all but for their larvae, which are like those of other crustaceans (Fig. 117). Barnacles are the much modified descendants of free-swimming crustaceans. Their larvae alone have not changed much.

A FAMILY TREE. The instances given above are a very small selection out of the great number of facts which point to the existence of evolution. All plants and animals alive to-day are twigs of a vast family tree. Present-day plants and animals are descended in direct lines from others now extinct and different from themselves. Generally speaking, the living end branches of the family tree are composed of species more specialized than their ancestors. Whales and bats, for instance, had ancestors less specialized and more like other mammals.

Some animals or plants have changed more, others less, in the course of time from what their ancestors were. Man and apes, for example, certainly both belong to the same stock. In anatomy they are very much alike. But in the course of evolution man has changed more from the common ancestor of both than apes have done. There is definite evidence for this from fossil remains of man, once called "missing links", now no longer missing.

*Hydra* is the simplest many-celled animal which we studied. It has evolved much less from the common ancestor of all many-celled animals than molluscs, arthropods or vertebrates have done.

The same fact comes out if we consider the vertebrate animals as a whole. We have seen that there is evidence that the remote ancestors of all of them were fish-like.

Modern fishes have not altered so very much from these ancestors. Amphibians have altered considerably more, but still they have fish-like tadpoles. Reptiles, birds and mammals have changed much more in the course of their history.

THE CONQUEST OF THE LAND. The evolution of the various classes of vertebrate animals other than fishes has been in the direction of better and better capacity for living on land. Amphibians are not so very different from fishes. Not only are they still dependent on moisture when adult but their larvae (tadpoles) live in water. Reptiles, birds and mammals can live in quite dry air. It is birds and mammals which have moved farthest in evolution, with their constant internal temperature and their superior brain power.

The fossil evidence altogether confirms this sketch of vertebrate evolution deduced from structure and physiology. You have seen (Chap. XVIII) how the different classes of vertebrates appeared successively on the earth. First came fishes and then amphibians. After the amphibians, reptiles appeared, then mammals and birds, and finally man. But the family tree had many side branches which stopped long ago. Many lines of evolution went on for a time and then died out. The different kinds of huge reptiles in the Secondary Era supply good examples of this.

LIFE BEGAN IN THE WATER. Fossils show us how in turn amphibians, reptiles and mammals, ending with man, were masters of the land. Anatomy and physiology show us how each of these kinds of vertebrate animals is in turn more and more suited to land life.

The ancestors of all the vertebrates were fish-like. They lived in water. So, too, the simplest animals of all, the protozoa, live in water. From some protozoan the ancestor of all many-celled animals evolved. This ancestor must have been something like *Hydra,* and it too was aquatic. Now, it is a fact that most groups of animals still live in water. Anemones, star-fishes, oysters, octopus, crustaceans and fishes are water-living. It is from aquatic ancestors that the land dwellers are descended.

Two groups of animals only, namely the arthropods and the vertebrates, have completely succeeded in conquering the land. Insects and land vertebrates are equally fitted to life in air, each in their own different ways. Among the molluscs, the snails have evolved into land dwellers, but they can hardly be said to be so successful as insects and spiders, or reptiles, birds and mammals.

PLANT EVOLUTION. On the plant side there is a similar story of gradual domination of the land environment. The lowest plants, bacteria, yeasts and algae, live in water. They have not evolved very far from the ancestors of all plants. Mosses and liverworts are more fitted to land and ferns even better. But still water is necessary for their spermatozoids. It is the flowering plants, with their ways of avoiding water loss, and their seeds and pollen, which are most fully adapted to land.

Now, the fossil history of plants tells how the evolution took place. After the lowest plants, liverworts and mosses appeared first on the earth. Then came ferns, later on pines, and lastly the flowering plants. Just as with the classes of vertebrate animals, first the lower (flowerless) plants and later on the higher (flowering) plants were in turn dominant on land. And each group of plants had many side lines in its family tree, which flourished for a time and then died out to give way to more perfect land plants.

THE BEGINNING OF LIFE. What were the ancestors of all animals and plants like? What were the first forms of life to appear on the earth and start the family trees of animals and plants? We do not know.

There are two reasons why we cannot know this. Undoubtedly the earliest forms of life must have been something like bacteria or protozoa. But they must have been too soft to leave fossil traces. And, moreover, the oldest strata of rocks formed of sediments laid down in water have been changed and re-crystallized by heat and pressure (p. 297). Consequently all fossils in them have been destroyed. So no traces are left of any of the earliest forms of life.

To-day, as far as we know, no living organisms can arise from anything non-living (p. 84). But at least once in the early history of the earth this must have happened. Presumably the chemical and physical conditions in the waters of the earth at that moment were different from anything we have been able to imitate in a laboratory. The conditions then must have particularly favoured the production of simple cells from non-living chemical substances.

## II. THE CAUSES OF EVOLUTION

There is no doubt of the fact of evolution. But for what reasons have plants and animals evolved? What has caused them in the course of ages to change from one kind into another?

CHARLES DARWIN. As far back as the time of the ancient Greeks scientific men suspected the existence of evolution. But biology was not sufficiently far advanced to prove it. Then the idea disappeared, and right through mediaeval times it was believed by everyone that all kinds of living animals and plants had been created some few thousand years ago. Fossils were still unknown and the real age of the earth was unsuspected. But after the Renaissance, plants and animals came to be better and better known. Anatomy was more deeply studied and more and more different kinds of living organisms were described. Then gradually suggestions of the existence of evolution were thrown out. But it remained for Charles Darwin (Fig. 151) to prove its reality.

In 1859 Darwin's book called the *Origin of Species* was published. In a very short time it had convinced biologists of the truth of evolution. The great power of Darwin's book was due to two circumstances. First, he gave a great

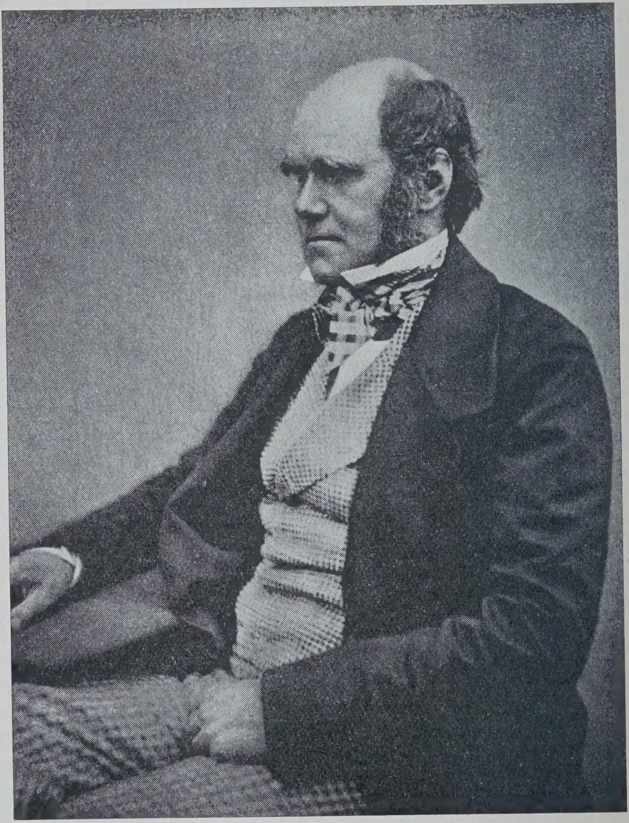

Fig. 151. *Charles Darwin.* Portrait taken about 1854.

wealth of evidence, of the sort which we have outlined in this chapter, pointing to the existence of evolution. And second, he proposed a theory to explain the causes of evolution.

By 1859 the minds of scientific men were ripe for the idea of evolution. Astronomy had already shown that heavenly bodies evolve. Planets and the sun, for instance, started as one. Fossils had been studied, and there were innumerable facts of anatomy waiting for a logical explanation. But one of the reasons for the immediate success of Darwin's book was that it not only demonstrated the existence of evolution but it also suggested a reasonable explanation of why plants and animals evolve.

Darwin's proof of the *reality* of evolution remains unshaken to-day. We have given an outline of it in the first part of this chapter. His theory of the *reasons why* evolution takes place has been added to and altered since his time. In essence Darwin's theory of the reasons why evolution occurs is most probably correct, but many gaps still remain to be filled in. We shall now briefly look into the question of the causes of evolution.

HEREDITY. A child inherits characteristics from its father and mother, and from its ancestors. There is a family resemblance between the generations. The same applies to animals and plants. Strains of garden flowers and lines of race horses are familiar examples. This is the fact of heredity.[1]

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[1] Each individual starts life as one cell, the fertilized egg. This divides many times until the full grown body is formed. Some of the cells resulting from the numerous successive divisions of the fertilized egg become testis or ovary. The remainder make all the other tissues of the body. It is from cells out of testis or ovary that the next generation will arise, from spermatozoa and eggs. This fact makes one look at heredity in a different light from the man in the street. Suppose, for instance, that a mother and a child both have blue eyes. The child has inherited its mother's eye colour. But this does not mean that the cells in the mother's eye had anything to do with the child's eye colour. For all the cells in the child's body, including the cells of its eyes, arose from a cell in the mother's ovary, not from cells in her eyes. In other words, both mother's eye and

Of late years a great deal has been discovered about heredity. It is possible to foretell, for example, when one parent has dark eyes and the other light-coloured eyes, what proportion of the children will have light eyes. A large number of facts of this sort have become known since the first discoveries of Mendel, an Austrian abbot, in the second part of last century. A whole branch of biology called *Mendelism* has grown up dealing with these facts of heredity. But we can go no further into the question here.

VARIATION. Brothers and sisters are never exactly alike. Offspring of animals or plants always show differences among themselves. These differences are called *variations*. Brothers can vary in all details of bodily structure. Their noses may be of different shapes. Their hair may vary in colour. They may be of varying heights. In the same way members of a family can show variations in the functions of the body. One brother may be more resistant to disease than another or he may form conditioned reflexes more rapidly.

Generally speaking, variations are due to one of two causes. Partly they are inborn. In other words, they are due to *heredity*: they are *inherited*. And partly variations are due to the life the individual has led. That is, they are caused by the *environment*.

Take the case of height. There are tall families of men and there are short families. On the average a member of a tall family will be taller than a member of a short family. But the exact height to which any member of a family grows will depend not only on his heredity. It will depend also on whether he was well fed or badly nourished as a boy. It may depend on whether or not he suffered serious illness.

child's eye are derived from a line of cells which has passed from generation to generation through the ovaries. That is to say, the body of a parent does not hand on its characteristics to the body of the offspring. Both bodies have like characters because both arise by cell division from a line of cells which can be traced through ovaries and testes back to far off ancestors.

So too for plants. There are tall and short strains of corn. But the exact height reached by any plant will depend also upon the amount of moisture and food salts in the soil. Both heredity and environment tell.

Occasionally quite *new variations* turn up in a family and are passed on by heredity to succeeding generations. Some detail of structure or of functioning of an organ which had never before been known in the family history appears. A strain of rabbits may have been bred for generations having always the same coat colour. And then suddenly a few individuals turn up with differently coloured hair. Flowers may have been raised for generations and then unexpectedly a few plants appear with an unusual number of petals. Such new and unexpected variations are called *mutations*. Once they have appeared they are passed on from parent to offspring by heredity. Up to now we know very little of the causes of mutations.

THE STRUGGLE FOR EXISTENCE. Many more plants and animals are born into the world than can possibly survive. You will remember how rapidly bacteria multiply (p. 81). A single pair of flies can produce 20,000 larvae. In a fortnight these turn into flies and breed again. If all survived they would then give rise to 100,000,000 more larvae. A single cod lays several million eggs. But of these, on the average, only two survive to grow into adult fishes. For neither flies nor cod are on the increase in numbers. So on the average only two offspring of a pair of parents can survive to replace their parents when the latter die.

This is true of all animals and plants, whether they have very numerous offspring like the cod, or only a few. Most members of each family die young. They are either killed by enemies or they die for lack of food. Of all the seed scattered by a flower only very few can grow into new plants. Most are crowded out. There is no room for them in the soil.

You have read how the prickly pear and how the rabbit suddenly multiplied enormously in Australia where they were free from their natural enemies (p. 138). Camels are becoming a nuisance in parts of Australia to-day for the same reason.

But normally hard conditions of life and enemies keep down the numbers. There is a never ending *struggle for existence*. Obviously in this struggle the weakest go to the wall. Individuals not vigorous enough to get most food go under. Those which are the strongest to fight foes or strongest to resist parasites live on and breed, while the weaker members of each family die young. In other words, the result of the struggle for existence is a *survival of the fittest*.

NATURAL SELECTION. Darwin saw that the struggle for existence should result in evolution. To quote Darwin's own words:[1]

> Let us take the case of a wolf which preys on various animals, securing some by craft, some by strength, and some by fleetness; and let us suppose that the fleetest prey, a deer, for instance, had from any change in the country increased in numbers, or that other prey had decreased in numbers, during that season of the year when the wolf was hardest pressed for food. Under such circumstances the swiftest and slimmest wolves would have the best chance of surviving and so be preserved or selected.... I can see no more reason to doubt that this would be the result than that man should be able to improve the fleetness of his greyhounds by careful and methodical selection, or by that kind of unconscious selection which follows from each man trying to keep the best dogs without any thought of modifying the breed.

Those individuals which survive to breed must be the strongest, the healthiest, the most cunning. Now, we have seen that these characters of strength, health or cunning are due to two causes. In part they are family characteristics. That is to say, they are inherited. And in part they are due to outside influences, to the life the growing animal or plant has led. Variations, in other words, are due partly to heredity, partly to environment.

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[1] *Origin of Species*, chap. IV.

The result of natural selection is that those animals or plants survive which are best fitted to the life they have to lead. Now, when the survivors breed they will hand on to the next generation *some* of the characteristics which helped them to win in the struggle for existence. Those beneficial qualities *which are hereditary* will reappear in the next generation. In this way, generation by generation, any species of plant or animal must get better and better adapted to its environment. Or, if no further improvement in adaptation is possible, the high level of efficiency will be kept up.

One of the most striking things which the study of biology brings out is the amazing degree of *adaptation* in all animals and plants. In ways that are often extraordinarily complicated they are fitted to the lives they lead. Think only of flying animals, of the bee state, of cross-pollination of flowers, of distribution of seeds, of the leaf insect (p. 133). Natural selection provides an explanation of this adaptation.

THE EVOLUTION OF NEW SPECIES. So far you see how the survival of the fittest will maintain the efficiency of a species. But how does it help to explain the evolution of one species into other species in the course of time?

We must remember that the environment is not unchanging. In the course of millions of years there have been several cold periods and several tropical ages in northern Europe (p. 291). We know indeed that climates change in much shorter periods of time. The Thames at London no longer freezes over as it once did. As these changes slowly occur plants and animals must change too.

If they are to survive they must adapt themselves to the new conditions.

As the environment alters, natural selection will pick out new characteristics which previously had no value in the struggle for existence. Some characteristics, of course, will count for survival in the new climate which are due only to the action of the environment on the individual during its life. As these characters are not passed on to the next generation they will not count in evolution. But if an *inherited* character happens to fit the individual better to the new climate, then it too will be selected in the struggle. Individuals possessing the particular characteristic will survive and they will pass it on to their descendants. Thus gradually a species will alter in many of its characters. It will turn into a new species by the *natural selection of favourable inherited variations.* If you remember that from time to time *mutations,* that is to say *new* inherited variations, turn up, you will see that there must be ample material for natural selection to work upon and so produce new species.

ACQUIRED CHARACTERS. Of course, to a large extent living organisms are able to adapt themselves to changes in their environment during their lifetime. If a man adopts the calling of blacksmith his arm muscles are developed more than those of other men. Will his sons, even if they are not blacksmiths, have arm muscles abnormally large? Or, if they adopt the calling of blacksmith, will their muscles develop more quickly than their father's did?

Now, were it true that such characteristics *acquired* in the lifetime of a plant or animal could be inherited by its offspring, then this would supply a good explanation of evolution. As an environment, a climate for example, gradually changed, each succeeding generation would develop adaptations to the altered world (just as the blacksmith develops his arm muscles) and pass them on to their successors. But it is uncertain whether this does happen.

Evolution seems to work by the more roundabout way of the natural selection of mutations. For reasons we do not yet know, cells in testis or ovary are changed from time to time. This results in new characters, mutations, in the next generation. If the new characters are favourable in the struggle for existence, their possessors survive to pass them on to their offspring. Natural selection seems to be a sieve which separates good from bad mutations by killing off the bad.

HUMAN EVOLUTION. This question as to whether or not characters acquired in the course of a lifetime are passed on by heredity is of immense importance, too, in considering human evolution. For with civilized man, natural selection no longer has full play. The weakest are no longer allowed to go to the wall. The weakest have families just as well as the fittest. One of the few ways in which natural selection can work to-day is by the death of those less resistant to diseases.[1]

But for generations now there have been schools, universities, trades. Does each generation pass on something of what it has learnt to its sons and daughters? There is no certainty that this happens. It is true that knowledge advances. But the advance accumulates in libraries. We are apparently no cleverer than our great-grandparents were.

ANIMAL AND PLANT GEOGRAPHY. Different regions of the world have different faunas and floras. This would be expected as a result of evolution. Climates and conditions of life differ, and so in each region different animals and plants have evolved to suit the varied circumstances of life. Contrasted climates have contrasted forms of life. But there are a number of curious exceptions. These are puzzling at first, but when the geological history of the countries is known the explanation becomes plain.

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[1] And perhaps of those less agile in avoiding motor cars.

Places quite near to one another, having climates very much alike, may yet have quite different animals. This is the case of Australia and New Zealand. Australia has numerous mammals, all of a peculiar kind related to the kangaroo. New Zealand had no mammals at all until man brought rabbits and domestic animals there. The reason is that for long ages past Australia and New Zealand have been separated by sea. Evolution has gone its own independent way in each country. The animals of England and China are much more alike, although the two countries are so far apart, but there has been no barrier to prevent land animals spreading between these distant countries. Even the faunas of north Africa and southern Europe are not unlike one another, but in the late Tertiary Era there was a land bridge across the Mediterranean.

It is clear, then, that like climates do not necessarily have like forms of life. Animals or plants start evolving in one region, and, if barriers prevent them from spreading, their descendants stay there.

There is another strange fact about the distribution of animals which only evolution and geology can explain. The kangaroo and its relations flourish in Australia. Opossums, which are their relations, are found in America. Nowhere else in the world does this group of mammals live. Yet Australia and America are widely separated by seas. Again, a strange mammal called the tapir, which you can see in the Zoo, lives only in Borneo and in Central America. Yet the barriers to spreading between these places are enormous.

Why are these nearly related animals found only in such remotely separated places? The answer is that in early Tertiary times kangaroo-like and tapir-like animals lived all over Europe, Asia and North America. Their fossil remains have been found. In the struggle for existence they have died out everywhere except in the isolated spots where they survive to-day.

## *CHAPTER XX*

# THE HISTORY OF BIOLOGY

GREAT advances in science have been made in the last century. These advances have been equally important in physics, in chemistry and in biology. Not only have we come, in this short space of human history, to understand much better than our ancestors ever did what the world around us is and what we are ourselves; but also, as a consequence of the scientific discoveries of this last century, civilization has been completely altered. It is biology which has made the most important contribution. For, thanks to medicine and hygiene, conditions of life are far better to-day than they have ever been before. Whether the other changes in civilization are equally good can be debated.

Neither art nor philosophy have advanced as science has done. The ancient Egyptians, and even prehistoric man who drew pictures on the stone walls of caves, were as much artists as any who have lived since their time. Greek philosophers were as great as any of their successors. Nor are the men of science who have brought about the great additions to knowledge in the last hundred years or so any cleverer than men who lived in ancient Greece. The recent remarkable progress in all the sciences has been possible thanks to the work of men of genius in past centuries. Gradually the discoveries which these men made have accumulated in libraries. More and more stepping stones have been laid down from which fresh advances could be made. The front gradually widened until, quite recently in history, there was ground and opportunity for numerous scientific men to apply their genius.

To understand how the main facts of biology outlined in this book have been found out, and how the interpretations of these facts have been arrived at, it is essential to know quite briefly what were the preliminary discoveries made in the past and who were the men that made them. These men are at least as important in human history as those who won battles or made laws.

ARISTOTLE. The earliest biologist of first-rank importance known to us is Aristotle. We may say without exaggeration that no later biologist has been a greater genius.

It is true that we know little of those who came before Aristotle. But there is reason to believe that few important discoveries had been made and that Aristotle had no libraries to consult which gave accounts of earlier work. We are thus amazed at the number of discoveries he made and at the insight he acquired into the structure and life of animals and plants.

Aristotle lived in the fourth century B.C. When a young man he became a pupil of the philosopher Plato at Athens. Plato taught his pupils in a grove of trees. This school of his, corresponding to a university, was known as the Academy. After this, Aristotle spent a long time in studying marine animals and other forms of life. Part of his work was done during a two years' honeymoon in the island of Lesbos. Then he was invited by Philip of Macedon to be tutor to his son Alexander, afterwards to become Alexander the Great. Aristotle accepted the post. Later on he returned to Athens to found his own college or university. This was called the Lyceum. Aristotle is said to have paid particular attention to dress.

It is impossible to give a full account of Aristotle's numerous works. He studied many plants and animals. Dissections were made, for instance, of the excretory and reproductive organs of mammals. He gave an account of the development from the egg of the octopus and of the chick. He explained that porpoises, like whales, are mammals. And he was not merely an observer. All along he formed theories to explain the facts.

Aristotle was chiefly concerned with the nature of life itself, with that which distinguishes the living from the non-living. He divided living organisms into vegetative, animal, and rational. The first, plants, have only the primary characteristics of life: nutrition, growth, and reproduction. Animals, in addition, have sensation and motion. And man, a rational being, directs his actions by his thoughts. Life is considered by Aristotle to be mind in different degrees of perfection. This went together with the conception of a scale of life, a classification of nature, from the non-living, through plants and lower and higher animals, to man.

PLINY. In the Roman Empire there were two outstanding figures in the history of biology. The first of these two was Pliny. He was a patrician and an important government official. At the same time he was an enthusiastic amateur naturalist. Pliny was an extremely hard worker, reading or dictating books even while he dressed after his bath. He was killed in the eruption of Vesuvius which overwhelmed Pompeii.

Yet Pliny was not a true naturalist, but rather a collector of facts and stories. These he put together in a famous work on Natural History, in thirty-seven books. It was quoted during the next thousand years as if all that was in it were true. This, however, was far from being the case, for Pliny was very credulous and mixed together truths based on observation with mere travellers' tales and superstitions.

One of Pliny's points of view is still frequently met with among people who have had no biological education, namely that every plant or animal must be of some use to man. We often hear such a question asked as "What good do cockroaches do?" It is assumed by those who ask such questions that the universe exists for our convenience. Now, some animals may incidentally be of use to man, as, for instance, earthworms (p. 123). But the biologist knows that all living organisms, including man, have evolved, and that all of them have their own lives to live.

Galen. The second of the two biologists in Rome who had a great influence on the science for many centuries after his death was Galen. He was a medical man. At one time he was a surgeon to gladiators, and, later on, physician to the Emperor Marcus Aurelius.

The human body had been dissected in schools of medicine before then. In Galen's time, however, this was no longer practised. But Galen was a very original investigator and he dissected numerous animals, particularly monkeys, which he realized were nearest to man in structure. He made many important discoveries, particularly in the anatomy of muscles and bones, and in the physiology of the spinal cord.

Yet one of Galen's chief errors must be mentioned, because it had such a great effect in later centuries when all that he had written was believed to be infallible. He did not realize that the blood circulates round the body. He thought that blood ebbs and flows both in arteries and veins. He believed, further, that air passes from the lungs into the heart where it charges the blood with a "vital spirit", and that in the brain the blood receives an "animal spirit".

The decline and re-birth of biology. From the end of the second century A.D. there was no science in Europe for over a thousand years. The works of Galen and Pliny were merely copied and re-copied, each time with more and more alterations and corruptions.

In Greece and Rome botany had been studied as a part of medicine. Descriptions were made of those plants used as medicinal herbs, and some of the herbals, as these descriptive works are called, were surprisingly accurate and well illustrated. They, too, were copied many times during the Middle Ages, until finally the plants in them were practically unrecognizable. For the plants themselves were never looked at in preparing new editions.

But after the seventh century, culture revived in the growing Mohammedan Empire, and Arabic now became the cultural language. The works of the Greek philosophers and scientists were translated into Arabic. Europeans now began to translate Aristotle and other Greek authors from Arabic into Latin.

Then universities were founded, of which Paris was at first the most important. Here old texts were studied, yet still without any new observations on plants or animals. But in Italy human dissection was begun again, after an interval of over a thousand years.

In the fourteenth century came the Renaissance, which was a re-birth both of art and of science. Nature was once more studied closely. In this the artists were at first the best observers. You will realize this by looking at the plants in the paintings of *Botticelli* and the animals drawn by *Dürer*. One great artist, *Leonardo da Vinci*, was at the same time a man of science. His drawings of human anatomy were not only accurate, but they showed the muscles as they are in life, not dead as seen in some modern books on anatomy. Leonardo was the first to compare correctly the limbs of the horse and man (Fig. 126), and he studied the way in which an image is formed on the retina of the eye (Fig. 138).

In the fifteenth century printing began. Greek works, including those of Aristotle, were now translated directly into Latin. And from this time on, the discoveries by men of science could easily be read by students and by other investigators.

WILLIAM HARVEY. In the period from the reign of Elizabeth to that of Cromwell there lived a man who can be said to be the founder of animal physiology. His name was William Harvey. He at last discovered how the circulation of blood around the body takes place, and put right Galen's errors.

Harvey was educated at Gonville and Caius College. The portrait of him reproduced in Fig. 152 hangs in the College.

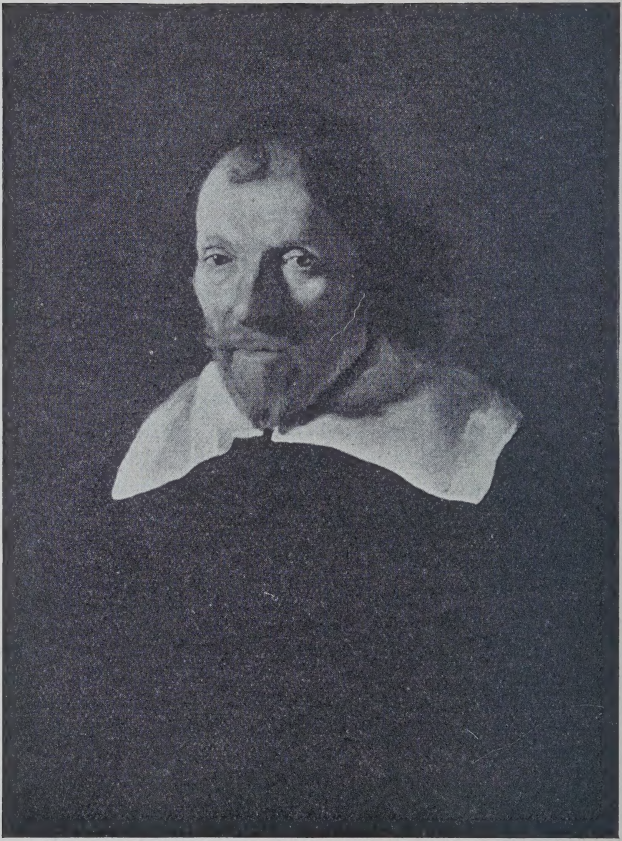

Fig. 152. *William Harvey.*

On leaving Cambridge, Harvey went on with his studies at Padua in Italy, at that time the most famous school of anatomy in Europe. Later on, Harvey was physician in turn to James I and Charles I, just as Dr Caius, the second founder of Harvey's college, had been physician to Edward VI, to Mary, and to Elizabeth. Harvey accompanied Charles I in one of his battles against Cromwell.

Harvey studied the heart not only in vertebrates but also in insects, in the oyster, and in the transparent shrimp. He explained the mechanism of the mammalian heart as a double pump. He concluded that the large volume of blood continuously being pumped by the heart into the aorta must come back again to the heart. Thus he deduced that there must be capillaries in all the tissues, leading from arteries to veins. Yet the microscope had not yet been invented, and he could not see capillaries as you have done.

THE MICROSCOPE. In the seventeenth century biology made great progress, largely owing to the invention of the microscope. Lenses and spectacles had long been known, but it was not until early in the seventeenth century that *Galileo* made the first telescope and the first microscope. The discoveries in astronomy due to the telescope were no more astounding than those in biology due to the microscope. A whole new world was opened. Among those who made the first discoveries with the new instrument the names of several men have become famous. Of these we shall mention only two.

One of them is *Robert Hooke*. He saw that the microscope would "make some men excel others in their observations and deductions almost as much as they do the beasts". Hooke did more work as a physicist than as a biologist, but his microscopical work was admirable. He gave the name to the "cell" (p. 50), and studied the structure of feathers (Fig. 130). He had an irritable temper.

*Malpighi*, who also lived in the seventeenth century, was a Professor of Medicine in Italy. But he was much more than a medical man. You know him already by his picture of the mistletoe (Fig. 28). This picture shows a section through a branch with the root of the parasite growing into it. Malpighi studied numerous other plant tissues under the microscope. He described the capillary blood vessels in the frog's lung, thus completing the great discovery of Harvey, just four years after the latter's death. He dissected silkworms, saw their complicated anatomy, and was astonished at it. Here he found tracheae and concluded correctly what is their function (p. 130).

Scientific societies. It is clear now that there was a great advance in science in the seventeenth century. One consequence of this was a need for scientific men to meet together and discuss their problems and results. Thus scientific societies came into being.

In the reign of Charles II a group of men, one of whom was *Robert Boyle* (see Preface), founded the *Royal Society of London*. This is to-day the premier scientific society in England, having its rooms in Burlington House. It was at first called the Invisible College, and consisted of "divers worthy persons inquisitive into natural philosophy". At about the same time the *Académie des Sciences* was formed in Paris. This was during the reign of Louis XIV.

Classification. More and more animals and plants were now becoming known. This was due in part to the use of the microscope, in part to collections brought back by travellers. Consequently there was an urgent need for classifying the rapidly accumulating material. Hitherto plants had scarcely been classified into groups and families at all. And no one had improved on Aristotle's system of grouping animals.

The necessary classification was done in the eighteenth century by a Swede, *Linnaeus*. He arranged all known plants and animals in groups according to their resemblances in structure. To him is due the exact idea of genus and species (p. 216).

Linnaeus started his career as a student of medicine. Then he went on foot on an expedition through Lapland to collect plants, travelling nearly 5000 miles and undergoing many hardships. Later on he became Professor of Natural History,[1] and sent out pupils on further expeditions. After his death his books were bought by a wealthy English naturalist. A Swedish warship was sent in pursuit of the vessel bearing away the library, but the English ship was faster and the books are still in London.

COMPARATIVE ANATOMY. The next great advance in biology was the study of plants and animals from the *comparative* point of view, the point of view taken throughout this book.

The poet *Goethe,* who was not only a poet but also a biologist, was one of the first persons since Aristotle to see clearly that numerous animals have a *uniformity of plan* in their structure. He regarded plants from the same viewpoint. The parts of flowers, for example, are modifications of leaves (p. 158), and so are cotyledons.

Goethe lived in Napoleonic times. A contemporary of his, *Baron Georges Cuvier,* studied the anatomy of animals from the comparative point of view. In particular, he studied fossil vertebrates. He was really the founder of this branch of biology.

Only a century before Cuvier's time had it become generally recognized that fossils are the remains of extinct animals buried in what were once marine muds and sands. *Robert Hooke* explained the matter correctly. Before his time, however, fossils were believed to have been created as we find them in the rocks. Some even said that they were put into the rocks by the Devil to deceive man. Yet as far back as the end of the fifteenth century *Leonardo da Vinci* had understood the nature of fossils.

Cuvier made enormous strides in the study of fossils and in the comparison of them with living animals. Many people were incredulous of his findings. On one occasion he started to chip a fossil out of a rock found near Paris. From the first view of the jaw he saw that it was the skeleton of an animal related to the kangaroo, now living only in Australia (p. 316). He called together a group of scientific friends and told them what the skeleton would be when he had extracted it from the rock. To their amazement he was right.

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[1] This includes Botany, Zoology and Geology. It is only within the last fifty years or so that the word Biology has been generally used, in place of the older term Natural History, for Botany and Zoology.

PHYSIOLOGY. In the seventeenth century *Robert Boyle* invented a vacuum pump. With his "pneumatical engine", as he called it, he showed that air is material and has weight. He put a mouse into the chamber of his pump and evacuated the air. The mouse died. By such means he proved that it is air, not some mysterious spirit, which is breathed.

A century later *Lavoisier*, one of the discoverers of oxygen, made exact experiments on breathing. He showed that carbon dioxide and water are the products of respiration. From this he concluded correctly that respiration must be an oxidation, and that the heat of the body is liberated by this oxidation. Lavoisier perished by the guillotine in the French Revolution.

In the first half of last century the famous chemist *Liebig* greatly advanced biology. He was a Professor of Chemistry in Germany. He classified the foodstuffs of animals into proteins, carbohydrates, and fats (p. 4).

For some time before this, plant physiology had been advancing, and it was now known that green plants absorb carbon dioxide from the atmosphere. Liebig taught what are called the carbon and nitrogen cycles (p. 83). He explained how plants feed on carbon dioxide through their leaves and on nitrates taken into their roots, and how these substances are returned to atmosphere and soil in putrefaction. But it was not yet known that bacteria are concerned in putrefaction.

One of the biggest advances at that time was due to a colleague of Liebig, who made (synthesized) urea (p. 23) in the laboratory. This was the first time that any chemical compound found only in living organisms had been made in the laboratory. It proved that there is nothing peculiar or mysterious in the power of protoplasm to build up special chemical compounds. Since then very many of the carbon compounds of animals and plants have been made in the laboratory.

Perhaps the greatest of the physiologists of last century was *Claude Bernard* of Paris. He studied and explained the complicated processes of digestion in the different parts of the alimentary canal. He found out how the blood supply to different parts of the body is regulated by reflex contractions of blood vessels (p. 268). All his work led him to regard the body as a most complex machine, each part depending on the activities of other parts, and the whole exactly regulated and controlled through nerves and blood. The work of Claude Bernard had a very great influence on those who came after him.

THE CELL. You will have realized early in your studies that the idea of the cell is immensely important in understanding the structure of living matter. Obviously nothing could have been known of cells until the microscope was invented in the seventeenth century. The earlier workers with the microscope, such as *Malpighi,* saw and drew cells. *Robert Hooke* gave the name to the cell. But it was not until 1839 that *Schwann* in Germany first realized that all animals and plants are composed of cells (p. 52). This was one of the milestones in the history of biology.

Schwann's work led to what was called the Cell Theory. This is no longer a theory but a fact. All plants and animals are made up of cells, and of their products such as cell walls, bone, and other secretions. The cell is composed of protoplasm, including the nucleus. Cells only arise by the division of pre-existing cells. And some animals and plants consist of one cell only.

BOTANY. Great progress was made in botany in the nineteenth century. On the one hand, *alternation of generations* came to be understood, and thus the relationship of the flowering plants to the lower plants was grasped. On the other hand, great strides were made in the subject of *plant nutrition.* You have seen how Liebig contributed to this.

Already in the eighteenth century it had been discovered that most plants absorb carbon dioxide and give off oxygen. Then it was found that only the green parts of plants absorb the carbon dioxide. Further progress, in the second half of last century, was largely due to the German botanist *Sachs.*[1] He showed that chlorophyll is contained in chloroplasts (p. 68). He proved that light is essential to the activity of chloroplasts in absorbing carbon dioxide. Then he demonstrated that starch appears in the chloroplasts when carbon dioxide is taken in. And, only 40 years ago, Sachs proved that the gas goes in through the stomata. He coated parts of leaves with wax, thus shutting the stomata, and found that, in sunlight, starch only appears in the uncoated parts.

EVOLUTION. Schwann's work on the cell, published in 1839, was of immense importance. An equally momentous event happened in 1859. In that year *Charles Darwin* (Fig. 151) published the *Origin of Species.* From then onwards evolution became the main idea running through biology. The conception of evolution has not only dominated biology but it has altered man's whole outlook on life. Darwin was the greatest biologist since Aristotle.

At the age of 23 Darwin embarked as naturalist on the *Beagle.* The voyage lasted five years, its object being a survey of South American coasts. Darwin was immensely impressed by the faunas of islands which were visited. He began to see that the peculiar species of animals and plants on the islands must be related by descent with other species on the mainland. And he found fossil animals resembling, but yet different from, living animals. All this started his train of thought which resulted in the revolutionary Theory of Evolution by Natural Selection.

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[1] Pronounced *Zachs*, with the *a* as in *father* and the *ch* as in the Scottish *loch.*

From the time the *Origin of Species* appeared in print until the close of last century zoologists were mainly concerned with studying the anatomy of animals and the development of their embryos, from the point of view of evolution. More and more evidence of descent was accumulated, and as far as possible family trees were drawn up. Among numerous eminent biologists of this period two names will be mentioned.

*Thomas Henry Huxley* (p. 9) was not only a great original investigator, making contributions to our knowledge of many groups of animals, but he also fought Darwin's battles for him, in lectures and in books. For, both inside and outside biological circles, the idea of evolution had to struggle against great opposition and prejudice, and Darwin himself was a retiring man.

The second name we shall mention is that of *Ray Lankester*, who died only in 1929. Lankester was professor in London and in Oxford, and was head of the Natural History Museum. He made many important discoveries in all branches of zoology. When only 17 years old he published the first complete description of the anatomy of the earthworm. Lankester had an impetuous temperament, but he always tried to share his knowledge with others and to inspire them with his own enthusiasm for biology.[1]

BACTERIA AND IMMUNITY. Schwann and Darwin have been spoken of as two men who had an enormous influence on biology in the last century. One launched the Cell Theory, the other the Theory of Evolution. There is a third very outstanding figure. This is *Louis Pasteur.* To him is due the discovery of the part played by bacteria in disease and of the facts of immunity. This means that he was the founder of modern medicine.

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[1] I recommend you to read Lankester's book entitled *Extinct Animals*.

It may interest some of you to know that on leaving school Pasteur was marked "mediocre in science" on what corresponds to our Higher Certificate, and that Darwin left Cambridge with a Pass Degree.

Early in his career Pasteur attacked the problem of *fermentation.* Schwann had already shown that living yeast cells are necessary for sugar to be fermented to alcohol. Pasteur showed that yeasts on the skins of ripe grapes are responsible for the grape juice turning to wine (p. 79). Further, he proved that the wrong kinds of yeast cause bad wines to be produced. This led him on to the immensely important discovery that *putrefaction* of dead animals or plants is a fermentation caused by bacteria. You will remember that Liebig had not realized this.

Putrefaction, according to Pasteur, must be due to bacteria carried by the air to dead bodies. But up till that time it had generally been believed that microscopic organisms arose by *spontaneous generation.* Bacteria were supposed to be produced anew by decaying matter. Pasteur disproved this by the experiment described on p. 84. Boiled soup remains sterile for ever if shut off from the air.

Next Pasteur was called in by the French Government to investigate a *disease* of silkworms which, in the 'sixties of last century, threatened to ruin the silk industry. He showed that the disease was due to bacteria. The same was found to be true of a certain cattle disease (anthrax). Bacteria were present in the blood of the sick animals. Meanwhile a method was devised of growing the bacteria in blood serum[1] outside the body of the infected animal.

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[1] Serum is the liquid remaining after blood plasma (p. 22) has formed a clot (p. 24).

These bacteria, inoculated into a healthy animal, then brought on the disease. This led to a knowledge of how infection occurs in nature (p. 85). *Lord Lister* at once appreciated the importance of Pasteur's discoveries and introduced antiseptics (carbolic acid) into surgery.

It was known already that a person is *immune* to measles after recovering from the disease. It was known also that persons can be made immune to small-pox by vaccination, that is by giving them a mild attack of a similar disease (p. 86). Pasteur showed that if you first heat bacteria of the cattle disease (anthrax) and then inoculate these bacteria into a healthy animal, the animal becomes immune to the disease. That is to say that if, later on, the animal is inoculated with enough bacteria (not previously heated) to kill an untreated animal, it shows no signs of disease. Thus arose the whole modern medical practice of bringing about immunity artificially by inoculation.

MODERN BIOLOGY. Pasteur's discoveries were made in the second half of last century. They were, as you know, among the most momentous events in the history of biology. In the middle of last century Darwin published the *Origin of Species*, an equally revolutionary happening.

From the time that Darwin's book appeared until the end of the century zoologists and botanists made many additions to our knowledge of anatomy and of development. Researches, such as those of Huxley and Lankester, were carried out with the ideas of evolution in mind. The results were used to show the degrees of relationship between different animals or plants. The new facts were fitted into schemes of descent from extinct ancestors.

By the end of the nineteenth century many of the most important facts of anatomy had been discovered and studied. To-day the main research activity is in the direction of physiology. We are finding out more and more how the living body works and how it grows. The physical and chemical nature of protoplasm is being explored. The relationship of living organisms to the world around them, the nature of the mind of animals, and the processes of heredity, are being investigated. At the same time research in biology is intimately connected with human affairs. Biological discoveries are continually being applied to advance medicine, public health, and agriculture.

Pope said that "the proper study of mankind is man". But we cannot understand the nature of man without a study of animals and plants as well. It is clear from all that has been said in this book that a knowledge of the main facts of biology is an essential part of the culture of every educated man and woman.

*THE END*

## *APPENDIX*

# GREEK AND LATIN DERIVATIONS OF WORDS

Abdomen: *abdo*, I hide.
Alga: *alga*, seaweed.
*Amoeba*: ἀμοιβή, change.
Amphibian: ἀμφί, on both sides; βίος, life.
Anatomy: ἀνατέμνω, I cut up.
Antenna: *antenna*, yard (in ship's rigging).
Anther: ἄνθος, flower.
Aorta: ἀείρω, I carry.
Arthropod: ἄρθρον, joint; πούς, foot.
Auricle: *auricula*, little ear.
Bacterium: βακτήριον, small stick.
Biceps: *bis*, twice; *caput*, head.
Biology: βίος, life; λόγος, science.
Capillary: *capillus*, hair.
Carpel: καρπός, fruit.
Cartilage: *cartilago*, gristle.
Chitin: χιτών, membrane.
*Chlamydomonas*: χλαμύς, cloak; μονάς, unit.
Chlorophyll: χλωρός, green; φύλλον, leaf.
Chloroplast: χλωρός, green; πλαστός, formed.
Chrysalis: χρυσός, gold.
Cilium: *cilium*, eyelash.
Crustacean: *crusta*, shell.
Diaphragm: διά, across; φράσσω, I separate.
Dinosaur: δεινός, terrible; σαῦρος, lizard.
Enzyme: ἐν, in; ζύμη, leaven.
Fibula: *fibula*, brooch.
Fungus: *fungus*, mushroom.
Gamete: γαμέτης, spouse.
Ganglion: γάγγλιον, swelling.
Geology: γῆ, earth; λόγος, science.
Gland: *glans*, nut.
Glucose: γλυκύς, sweet.

Glycogen: γλυκύς, sweet; γεννάω, I produce.
Haemoglobin: αἷμα, blood; *globo*, I make into a ball.
Hermaphrodite: Ἑρμῆς, Ἀφροδίτη.
Hormone: ὁρμάω, I stir up.
Ichneumon: ἰχνεύω, I hunt.
Ichthyosaur: ἰχθύς, fish; σαῦρος, lizard.
Incisor: *incido*, I cut into.
Iris: *iris*, rainbow.
Labium: *labium*, lip.
Larva: *larva*, ghost.
Mandible: *mando*, I chew.
Maxilla: *maxilla*, jaw.
Metacarpal: μετά, beyond; καρπός, wrist.
Metatarsal: μετά, beyond; ταρσός, sole of foot.
Molar: *molo*, I grind.
Mollusc: *mollis*, soft.
Monopodial: μόνος, single; πούς, foot.
Nucleus: *nucleus*, kernel.
Octopus: ὀκτώ, eight; πούς, foot.
Osmosis: ὠσμός, impulsion.
Ovary: *ovum*, egg.
Pancreas: πᾶν, all; κρέας, flesh.
*Paramecium*: παραμήκης, elongated.
Pepsin: πέπτω, I digest.
Perennial: *per*, through; *annus*, year.
Peristalsis: περιστέλλω, I constrict.
Photosynthesis: φῶς, light; σύνθεσις, combination.
Phylum: φῦλον, tribe.
Physiology: φύσις, living nature; λόγος, science.
Pistil: *pistillum*, pestle.
Plankton: πλαγκτός, floating.
Plumule: *pluma*, down feather.
Pollen: *pollen*, fine flour dust.
Protein: πρῶτος, first.
Prothallus: πρό, in front; θαλλός, frond.
Protoplasm: πρῶτος, first; πλάσμα, form.
Protozoa: πρῶτος, first; ζῶον, animal.
Pseudopodium: ψευδής, false; πόδιον, little foot.
Pterodactyl: πτερόν, wing; δάκτυλος, finger.
Ptyalin: πτύαλον, spittle.

Pupa: *pupa*, puppet.
Radicle: *radix*, root.
Reptile: *repto*, I crawl.
Retina: *rete*, net.
Rhizome: ῥίζα, root.
Saliva: *saliva*, spittle.
Saprophyte: σαπρός, putrefied; φυτόν, plant.
Sebaceous: *sebum*, tallow.
Serum: *serum*, whey.
*Spirogyra*: σπεῖρα, coil; γῦρος, ring.
Sporangium: σπορά, seed or spore; ἀγγεῖον, vessel.
Stamen: *stamen*, the warp.
Stigma: στίγμα, a spot.
Stoma: στόμα, mouth.
Style: στῦλος, pillar.
Sympodial: σύν, together; πούς, foot.
Tendon: *tendo*, I stretch.
Thorax: θώραξ, chest.
Thyroid: θυρεοειδής, shield-shaped.
Tibia: *tibia*, shin.
Trachea: τραχύς, rough.
Turgor: *turgo*, I swell.
Ulna: *ulna*, elbow.
Vaccination: *vacca*, cow.
Ventricle: *ventriculus*, little belly.
Vertebra: *vertebra*, joint.
Zoology: ζῶον, animal; λόγος, science.
Zygote: ζυγωτός, joined.

# INDEX

*Pages with illustrations are printed in italics*

Abdomen, 33, 126, *137*, 142, *219*, 244
Acquired characters, 314
Adaptation, 313
Age of fossils, 289
Air bladder, 232
Alga, 91
Alimentary canal, 5, *6*, *122*, *129*, *222*, *225*
Alternation of generations, 98, 101, 107, 159, *160*, 184, 328
Amino-acids, 8
*Amoeba*, 41, *42*, *46*, 57
Amphibian, 232, 296
Anaesthetic, 85
Anatomy, 25
Ankle, *29*, *31*, 32
Annual, 70, 206
Annual ring, *195*
Ant, 155, 178
Antenna, *127*, *137*, 140, *143*, *146*, *219*, *225*
Anther, 158–169
Antiseptic, 85, 331
Antitoxin, 86
Anus, *6*, *28*, *120*, *222*, *225*
Aorta, *18*, 20, 37, *38*
Ape, 278, 291, 304
Appendix, *6*, 302
Apple, 178
Apricot, 173
*Arenicola*, 124
Aristotle, 318
Artery, 17–24, *38*, *222*, *234*
Arthropod, 216, 272, 306
Aseptic methods, 85, 256
Ash tree, 176, *201*
Ass, 216, 300
Auricle, *18*, 19, *28*, *38*
Axil, *200*, *201*, *202*, *210*
Backbone, *29*, 30, *31*
Bacteria, 52, 65, *80*, 147, 330
Bark, *195*
Barley, 79, 185
Barnacle, *228*, 302, 304
Bat, 245, *246*, 300
Bean, 163, *179*, *180*, 185, *188*
Beaver, 275, 282
Bee, 151, *152*, *153*, 159–171, 274, 276, 278
Beech, 173, *205*
Beer, 79
Bernard, Claude, 327
Biceps, *33*
Bile, 36
Biological control of pests, 138
Bird, 36, *246*, *247*, 296, 300
Bladder, *6*, 23, *28*, 39
Blood, 8, 12–14, 17–24, 55, 146, 320, 323
Blood vessels, *18*, *38*, *234*
Blushing, 239
Body cavity, 36, 121
Bone, 29, 49
Botany, 1, 325
Botticelli, 321
Boyle, Robert, 324, 326
Brain, *6*, 34, *35*, 268, *269*, 294
Bread, 4, 79
Breathing, 12, 26, 121, 130, 144, *244*
Breast bone, *6*, *28*, 32
Broom, 174
Bud, *78*, *110*, *200*, *201*, *202*, *203*, *208*, *210*
Bulb, *210*, 211
Burdock, *177*
Buttercup, *157*, *158*, 173
Butterfly, 135, *137*, 159

Cactus, *70*, 138
*Calanus*, 226, *227*
Camel, 292
Cannon bone, 242, *292*
Capillary, *17*, 19–24, 26, *55*, *56*, *238*, 324
Capsule, *98*, 99
Carapace, 218, *219*
Carbohydrate, 4
Carbon cycle, 83, 326
Carnivorous animal, 72, 293
Carnivorous plant, 74
Carpel, 157–171
Carrot, 209
Cartilage, 29
Castor-oil plant, 181, *182*
Caterpillar, 134, *137*
Catkin, *170*
Cell, 50–57, *189*, 327
Cell division, *46*, 57, *116*, *258*
Cell sap, 95, 189
Cell wall, 50
Cellulose, 4, 50
Cereal, 183, 185
Cerebral hemisphere, *28*, 34, *35*, *269*
Chalk, 286, 289, *290*
Chameleon, *27*, 28, 237
Cherry, 178
Chestnut, 203
Chick, 254, 261
Chitin, 128, 131, 218
*Chlamydomonas*, 91, *92*, *93*
Chlorophyll, 60, 187
Chloroplast, 68, *69*, 91, *92*, *94*, 328
Cholera, 148
Chrysalis, 134, *137*
Cilia, 45, *48*
Classification, 214, 324
Clematis, *176*
Climate, 291, 313, 315
Clotting, 24
Clover, 1, 83, 163
Coal, *283*, 284, *285*, 289, *290*, 291, 297
Cockroach, 126, *127*, *129*, *131*
Coconut, 138, 177
Collar bone, *31*
Colour change, 26, *53*, *224*, 232, 235, 266
Colour sense, 276, 281
Conditioned reflex, 275
Cone, *171*
Conjugation, *88*, 89, *93*
Connective tissue, 55
Consciousness, 269, 280
Conservation of energy, 14
Contractile vacuole, *42*, 43, *47*, 49, 91, *92*
Control of blood supply, 24, 268, 327
Coral, *118*, 119
Cork, 50, 194, *200*, 204
Corn, 83, 175
Corpuscle, *17*, 21, 22, 52, 86
Cotton, 175, 185
Cotyledon, *179*, *182*, *184*
Cowparsnip, 169
Crab, 218, 224, *227*, 304
Crayfish, 218, *219*, *221*, *222*, 266
Crocodile, 237
Crop, *129*, 130
Crustacean, 216, 218, 223, 272
Currant, 173, 178
Cuticle, 68, *69*, 96
Cuvier, 325
*Cyclops*, 226, 302

Daisy, *167*, 199, 206
Dandelion, *168*, *176*, 199
*Daphnia*, 111, 224, *225*, 252, 302
Darwin, 123, 176, 177, *308*, 328
Date, 173
Dead-nettle, 165, *166*, 199, 217
Deer, 272
Diaphragm, *6*, 244
Diatom, 226
Digestion, 5, 41, 74, 187
Digit, 242
Dinosaur, 293, *294*

# INDEX

Disease, 24, 80, 84, 147, 330
Dog, 241, *243*, 272, 278, 299
Dolphin, 244
Dürer, 321

Ear, 26, 30, 34
Earthquake, 289
Earthworm, 13, 119, *120*, *122*, 132, 275
Eel, 237
Egg, 39, 112, *114*, 135, 141, 251, *253*, 255
Egg cell (plant), 96, *97*, 99, *105*, 106, 161
Electricity, produced by animals, 4
Elephant, 282, 292
Elm, 176, 195, 199
Embryo (animal), 252, 294, *303*
Embryo (plant), 173, *179*
Energy liberation, 8, 11–15, 43, 71, 78, 82
Energy source, 4, 8, 11, 60, 136
Enzyme, 7, 41, 74, 187, 240
Epithelium, *55*
Evergreen, 70, 207
Excretion, 23, 37, 84, 112
Exercise, 14, 24
Eye, 269, *271*, *273*

Faeces, 7, 39, *47*
Fat, 4, 8, 9, *28*, 49, 130, *238*, 245
Fatigue, 14
Feather, *247*
Femur, *29*, *31*, 32
Fermentation, 77, 81, 330
Fern, 101, *102*
Fertilization, 97, 99, 106, *114*, 131, 161, 251
Fibula, *31*, 32
Figwort, 168
Fin, *232*
Finger, *31*, 32
Fir, *171*
Fish, *3*, 13, *232*, *233*, *234*, 296
Flat-fish, 235, *236*, 304
Flea, *148*, 149
Fly, 139, *140*, *141*, 147
Food of animals, 4, 22, 41, 47, 136, 326
Food of plants, 59, 77, 82, 87
Food preservation, 83, 89
Food vacuole, 41, *42*, *47*
Frond, 101, *102*
Function, 25
Fungus, 89

Galen, 320
Galileo, 323
Gall bladder, *6*, 36
Gamete, 92, 95, 98, 101, 105, 161
Ganglion, *122*, 123, *129*, 130, *222*, *264*
Gastric juice, 5, 7
Genus, 216
Geology, 282, 325
Gill, 13, 124, 218, *230*, *233*, *253*, *303*
Giraffe, 272
Gland, *56*, 111, 119, *129*
Glottis, *28*, 36
Glucose, 8
Glycogen, 9, 11–14
Gnat, 142
Goethe, 325
Gorse, 174
Granite, 297
Grape, 79, 178
Grass, *164*, 199, 207, 211
Grasshopper, 133
Gravity, effect on plants, *180*, 191
Groundsel, 70, 206
Gullet, *6*, *28*, *47*, *225*, *233*

Haemoglobin, 21, 52, 121, 233
Hair, 49, *238*, 239
Hare, 272
Harvey, William, 21, 321, *322*
Hazel, 173
Heart, *6*, *18*, 19–24, *38*, 130, *222*, *225*, 323
Heat, effect on animals, 7, 26, 34

Heat, effect on plants, 70, 81, 83, 186
Heat, produced by animals, 3, 13
Heat, produced by plants, 7
Herb, 199
Heredity, 309
Hermaphrodite, 113, 121
Hip, *29*, *31*, 32, *241*
Honey, 153
Hoof, 242
Hooke, Robert, 50, 148, 247, 323, 325
Hormone, 23, 266
Horse, 216, *241*, 291, *292*, 299
Humerus, *29*, *31*, 32
Humus, 65, 123
Huxley, T. H., 9, 329
Hyacinth, 171
Hydra, 109, *110*, *111*, 304, 305

Ice age, *290*, 291
Ichneumon, 138
Ichthyosaur, *Frontispiece*, 294, 301
Immunity, 85, 331
Infection, 85, 331
Inhibition, 268, 269, 276
Inoculation, 24, 86, 330
Instinct, 272
Intelligence, 280
Intestine, *6*, *18*, *28*, *38*, *55*, *129*, *222*, *225*
Iris, 270, *271*

Jaw, *29*, 30, *243*
Jelly-fish, 112, *226*, *286*

Kangaroo, 316, 326
Kidney, *6*, *18*, 23, *28*, *38*, 39, 121, 130
Knot, 196

Labium, 128, *129*, 135, *137*, *146*
Laburnum, 163
Lankester, Ray, 329
Larva, 134, *137*, *140*, *143*, *148*, *153*, 226, *228*, 252
Larynx, *6*, 28
Lavender, 165
Lavoisier, 326
Leaf, 51, 59, 68, *69*, 192, 199, *285*
Leaf fall, 70
Leaf insect, *133*, 134, 313
Lens, 270, *271*
Lenticel, 201, *202*
Leonardo da Vinci, 321, 325
Lesser celandine, 158, 174
Liebig, 326
Light, effect on animals, 120, 226, 270, 272
Light, effect on plants, 1, *2*, 60, 186, *191*
Light, produced by animals, *3*, 26, 226
Lily, 171, 177
Lime, *176*
Linnaeus, 218, 324
Linseed, 185
Lion, 272
Lister, Lord, 85, 331
Liver, *6*, 8, 9, *18*, 22, *28*, 36, *38*, *234*
Liverwort, 96, *97*, *98*
Lizard, 36, 119, 237, 240
Lobster, 218, 226
Locust, 134
Louse, 149, *150*
Lung, *6*, 12, *18*, 19, 21, 26, *28*, *38*, *230*, 244, 248
Lupin, 163

Maggot, 139
Maize, 183, *184*
Malpighi, 73, 323, 327
Malt, 79, 187
Mammal, 237
Mammoth, 282
Mandible, 128, *129*, 135, *146*, 220, *221*, *222*
Marble, 298
Maxilla, *127*, *129*, 136, *137*, *146*, *221*
Meat, 4, 5, 33, 83

Medulla, 268
Melon, 173
Memory, 280
Mendelism, 310
Metacarpal, *29*, *31*, 32, *292*
Metatarsal, *29*, *31*, 32
Milk, 237, 239, 266, 302
Mint, 165
Missing link, 304
Mistletoe, *73*
Mollusc, 229
Monkey, 149, *279*
Monopodial branching, *202*, 206
Mosquito, *142*, *143*, *144*, *145*, *146*, 149
Moss, 99, *100*
Mould, 86, 89
Moulting, 132, 135, 218
*Mucor*, 86, *87*, *88*
Mucus, 45, 120, 230
Muscle, 11–15, *33*, 34, 112, *128*, 214
Mushroom, 89
Mussel, 47, *48*, *228*, 229, *230*
Mutation, 311, 314, 315

Natural selection, 312
Navel, 255
Nectar, 136, 159
Nectary, *158*, 159, 163, 165
*Nereis*, 124
Nerve, 30, 34, 130, 214, *238*, 263
Nerve cell, 112, 263, *264*, *269*
Nerve cord, 121, *122*, *129*, 130, *222*
Nerve impulse, 265
Newt, 26, 232
Nitrogen cycle, 82, 326
Nitrogen fixation, 82
Nucleus, 44, *47*, 52, *113*, 251
Nut, 173, 178

Oak, 195
Octopus, *231*, 318
Oil, 4, 181
Onion, 209
Orange, 173
Orchid, 174
Organ, 56
Osmosis, 43, 63, 214
Ostrich egg, 251
Ovary (animal), 39, *110*, 113, *129*, 131, *225*, 266, 309
Ovary (flower), 157–173
Ovule, 157–173
Oyster, 47, 226, 229

Palate, *6*
Palm, 185
Pancreas, *6*, 8, 23, *28*, 266
*Paramecium*, 45, *47*, 261
Parasite, 74, 84, 138
Pasteur, 84, 330
Pea, 70, 83, *162*, 185
Pearl, 230
*Pellia*, 96, *97*, *98*
Pepsin, 7
Perennial, 206
Peristalsis, 7, 33, 54
Petal, 157–171
Photosynthesis, 60, 72
Phylum, 214
Physiology, 25
Pine, 70, *171*, 206, 207
Pistil, 163
Plague, 149
Plane, 195
Plankton, 226, *227*, 245, *287*
Plasma, 22, 255
Pliny, 319
Ploughing, 65, 83
Plum, 173, 178
Plumule, *179*, *180*, *184*
Pod, 163, 173, *175*, 179
Poison gland, 237
Pollen, 153, 158, 171
Pollen tube, 159, 185
Pollination, 158, 163, *168*, 169, 171
Poplar, 175
Poppy, *175*
Porpoise, 244, 318
Potato, 4, *209*, 211

Prawn, 218, 221, 223, *224*, 226, 266
Primrose, *169*
Privet, *192*, 199
Protein, 4
Prothallus, *104*, *106*
Protoplasm, 49
Protozoa, 49, 216
Pruning, 205
Pseudopodium, 41, *42*, *258*
Pterodactyl, *246*, *295*, 300
Ptyalin, 7
Pulse, 20
Pupa, 134, *137*, 139, *140*, *144*, *145*, *153*
Pupil, 270
Pus, 86
Putrefaction, 82, 326, 330

Rabbit, 139, 243
Radicle, *179*, *180*, *184*
Radio-ulna, *29*, 32
Radius, *31*, 32, *33*
Reason, 278, *279*
Reflex, *264*, 265, 267, 272
Regeneration, 117, *215*, 221
Reptile, *27*, 237, 293, *294*, *295*, 301
Respiration of animals, 12, *16*, 43, 326
Respiration of plants, 13, 71, 123, 186
Retina, 270, *271*, *273*
Rhizoid, 96, *97*, 99, *100*, *104*
Rhizome, *207*, *208*, 211
Rib, *31*, 32, 244
Root hair, 63, 123
Rush, 177

Sachs, 328
Sage, 165
Saliva, 5, 7, 130, 267, 268, 275
Salivary gland, *129*, 146, 237
Salmon, 237
Sandhopper, 224
Saprophyte, 87
Scent, 159, 163
Schwann, 52, 327
Sea-anemone, *117*, 119
Sea-urchin, *114*, *116*, 216, *217*, 226
Seaweed, 91
Sebaceous gland, *238*, 239
Secretion, 56, 266
Sedge, 177, 207
Segmentation, 36, 123, 132, 223, 235
Sensation, 269
Sense organ, 34
Sepal, 157–168
Serum, 330
Shoulder, *29*, *31*, 32, *33*, *241*
Shrimp, 218, 223, 224, *225*
Shrub, 199
Silkworm, 134, 330
Skeleton, *29*, *31*, 34, *128*, 218, *241*
Skin, 26, 34, 37, 49, 120, *238*
Skull, *29*, 30
Smell, 120, 154
Snail, 229, *230*
Snake, 237
Snapdragon, 168
Soil, 64
Solomon's seal, *208*
Species, 216, 299, 313
Speech, 269
Spermatozoid, 96, *97*, 99, *100*, *105*
Spermatozoon, *113*, 154, 251
Spider, 216
Spinal cord, *6*, *28*, 30, 34, *35*, 268
Spine, *6*, *29*, 30
*Spirogyra*, *94*
Splint bone, 242, 291
Spontaneous generation, 84, 307, 330
Sporangium, *87*, 88, 99, *102*, *103*, 161
Spore, *80*, 81, 83, *87*, 88, 98, 99, *103*, 161

Sporogonium, *98*, 99, *100*
Stamen, 157–171
Starch, 4
Starfish, *215*, 216, 226
Sterile, 216
Sterilization, 83
Stickleback, 237
Stigma, 158–169
Stimulus, 44, 263
Stoma, *51*, 68, *69*, 328
Stomach, 5, *6*, 7, *28*, 110, *111*
Stratum, *288*, 289
Strawberry, 178, *211*
Struggle for existence, 311
Style, 158–168
Sugar, 4
Sundew, 73
Sunflower, 165, 185
Survival of the fittest, 312
Sweat gland, *238*, 239, 240
Sycamore, *177*, *201*, *202*
Symmetry, 162
Sympodial branching, *202*, *205*, 206, *208*

Tadpole, 26, 252, *253*, 267
Tapir, 316
Teeth, 30, 242, *243*
Temperature regulation, 23, 67, 239
Tendon, *33*
Tendril, 193, *194*
Tentacle, 109, *110*, *117*
Testis, *28*, 39, *110*, 113, *222*, 309
Thorax, 126, *127*, *137*, *143*, 218, 244
Thread cell, *111*, 112
Thyroid, 266
Tibia, *31*, 32
Tibio-fibula, *29*, 32
Tissue, 54
Tissue culture, 255, *256*, *257*, *258*
Toe, *31*, 32
Tongue, *6*, 26, *27*, *28*, 34
Tortoise, 237
Trachea (insect), 130, *131*, *140*, 144
Trachea (vertebrate), *6*, 19, 28, 36, 45
Transpiration, 67, 193
Tree, 193, *195*, 199, 206, *283*
Trout, 237
Trypsin, 8, 23
Tuber, 208, *209*, 211
Tuberculosis, 148
Tulip, 171, 209
Turgor, 63, 68, 193
Turnip, 209
Twig, 201–206
Typhoid, 148
Typhus, 149

Ulna, *31*, 32
Urea, 23, 39, 50, 327
Urine, 23, 39
Uterus, 255

Vaccination, 24, 86
Variation, 310
Vascular bundle, *66*, 101, 193, *200*
Vein (animal), 17–22, 37, *38*, *234*
Vein (leaf), 67
Vein (wing), 136, *137*
Ventricle, *18*, 19, 20, *28*, 37, *38*, *234*
Vertebra, *6*, *29*, 30, *35*
Vertebrate animal, 36, 232
Vestigial organ, 302
Vetch, 174, *175*
Violet, 174, *175*
Virus, 80
Viscera, 36
Vitamine, 5
Volcano, 297

Wasp, 274
Weller, Mr, 132
Whale, 244, *245*, 293, 301, 302
Wheat, 183, 185

Whelk, 229
Willow, *170*, 175
Wine, 79, 330
Wing, 126, *127*, *246*, 248, 300
Withering, 68
Wolf, 282, 312
Womb, 255
Wood, 49, 68, 193, *195*, 199
Wound, 24, 85, 259
Wrist, *29*, *31*, 32, *241*, *292*

Yeast, 77, *78*, 330
Yolk, 115, 252, 254

Zoology, 1, 325
Zygote, *88*, 89, *93*, *94*, 97, 99

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